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UTILITY PATENT APPLICATION TRANSMITTAL
(Only for new nonprovisional applications under 37 CFR 1.53(b))

Docket No.   :   39260/RAG/C766

Inventor(s)   :   Francis M. Reininger

Title   :   SPATIALLY MODULATED INTERFEROMETER AND BEAM SHEARING DEVICE THEREFOR

Express Mail Label No. :   EL521375682US

ADDRESS TO: Assistant Commissioner for Patents
Box Patent Application
Washington, D.C. 20231   Date: April 12, 2000

1.   X   **FEE TRANSMITTAL FORM** *(Submit an original, and a duplicate for fee processing).*

2.   **IF A CONTINUING APPLICATION**
     ____   This application is a   of patent application No. .

         Prior application information: Examiner ; Group Art Unit:

     X   This application claims priority pursuant to 35 U.S.C. §119(e) and 37 CFR §1.78(a)(4), to provisional Application No. 60/129,383.

3.   **APPLICATION COMPRISED OF**

Specification
     51   Specification, claims and Abstract (total pages)

Drawings
     19   Sheets of drawing(s) (FIGS. 1 to 19)

Declaration and Power of Attorney
     X   Newly executed
     ___   No executed declaration
     ___   Copy from a prior application (37 CFR 1.63(d))(for continuation and divisional)

4.   ____   **Microfiche Computer Program** *(Appendix)*

5.   ____   **Nucleotide and/or Amino Acid Sequence Submission** *(if applicable, all necessary)*
     ___   Computer Readable Copy
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6.   **ALSO ENCLOSED ARE**
     ____   Preliminary Amendment
     ____   A Petition for Extension of Time for the parent application and the required fee are enclosed as separate papers
     X   Small Entity Statement(s)
         ___   Statement filed in parent application, status still proper and desired

Docket No.: 39260/RAG/C766

_____ _____ Copy of Statement filed in provisional application, status still proper and desired

__X__ An Assignment of the invention with the Recordation Cover Sheet and the recordation fee are enclosed as separate papers

_____ This application is owned by pursuant to an Assignment recorded at Reel , Frame

_____ Information Disclosure Statement (IDS)/PTO-1449

_____ _____ Copies of IDS Citations

_____ Certified copy of Priority Document(s) *(if foreign priority is claimed)*

_____ English Translation Document *(if applicable)*

__X__ Return Receipt Postcard (MPEP 503) (should be specifically itemized).

_____ Other

7. **CORRESPONDENCE ADDRESS**

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Applicant or Patentee : Francis M. Reininger
Application or Patent No. :
Filed or Issued : April 12, 2000
Entitled : SPATIALLY MODULATED INTERFEROMETER AND BEAM SHEARING DEVICE THEREFOR

VERIFIED STATEMENT (DECLARATION) CLAIMING SMALL ENTITY STATUS
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I hereby declare that I am an official empowered to act on behalf of the nonprofit organization identified below:

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__X__ the specification filed herewith

_____ Application No. __ filed __

_____ Patent No. __ issued __

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If the rights held by the nonprofit organization are not exclusive, each individual, concern or organization having rights in the invention is listed below* and no rights to the invention are held by any person, other than the inventor, who would not qualify as an independent inventor under 37 CFR 1.9(c) if that person made the invention, or by any concern which would not qualify as a small business concern under 37 CFR 1.9(d) or a nonprofit organization under 37 CFR 1.9(e). *NOTE: Separate verified statements are required from each named person, concern or organization having rights to the invention averring to their status as small entities. (37 CFR 1.27)

NAME :
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-1-

VERIFIED STATEMENT (DECLARATION) CLAIMING SMALL ENTITY STATUS
(37) CFR 1.9(f) & 1.27(d) – NONPROFIT ORGANIZATION

Docket No.: 39260/RAG/C766

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I acknowledge the duty to file, in this application or patent, notification of any change in status resulting in loss of entitlement to small entity status prior to paying, or at the time of paying, the earliest of the issue fee or any maintenance fee due after the date on which status as a small entity is no longer appropriate. (37 CFR 1.28(b))

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SIGNATURE _____   DATE _12 April 2000_

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SPATIALLY MODULATED INTERFEROMETER

AND BEAM SHEARING DEVICE THEREFOR

CROSS-REFERENCE TO RELATED APPLICATION

5   This application is based on provisional patent application serial number 60/129,383 filed April 13, 1999.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

BACKGROUND OF INVENTION

        The present invention relates generally to beam
15 shearing systems and their applications, particularly in spatially modulated or static interferometers, which have low volume, low mass, high spectral resolution, a single instrument line shape function and are field widened.

        Interferometers are a class of instruments that
20 convert light from a source into an interference fringe pattern or interferogram. Interferometers make measurements on light within a certain portion of the spectrum. This portion is referred to as the predetermined spectral passband of the interferometer. Frequencies of light
25 outside of the predetermined spectral passband are

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attenuated so that they do not cause inaccuracies in measurements made by the interferometer.

Spatially modulated or static interferometers use a beam shearing system to shear the input beam into two separate beams and a Fourier optical system can be used to recombine the two sheared beams at a detector array or photographic plate. This procedure generates an optical path difference across the wavefronts of the recombined beams, which results in the formation of a modulation pattern that is fixed in space. If a two dimensional detector array is used, then it can record the spatially modulated pattern as an interferogram in one dimension of the detector array and an image in the orthogonal direction.

Static interferometers are distinguished from other types of interferometers in that they do not require the movement of an optical component or the observational platform to generate an interferogram. Interferometers that require the movement of the observing platform or an optical element to generate their spectrum over a given time interval are prone to unrecoverable spectral errors.

The first reported static interferometer was a Michelson interferometer with tilted mirrors built by G. Stroke and A. Funkhouser (see G. W. Stroke et al., Physics Letters, 1965, Volume 16, Number 3, Pg. 272). Two decades later, T. Okamoto et al used a triangular Sagnac interferometer and a conventional camera lens to generate an interferogram (see T. Okamoto et al., Applied Optics,

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1984, Volume 23, Number 2, Pg. 269). In all reported cases, traditional interferometer configurations and conventional Fourier Lenses have been used to generate the interferograms, and the detector arrays have operated in
5   the ultra-violet to near infrared wavelength regimes.

The ability to operate a static interferometer at longer wavelengths than those used by existing static interferometers would offer certain advantages. For instance, operation in the thermal-infrared spectrum would
10   enable fewer pixels to be used to sample the fringes of an interferogram because the frequency of fringes decreases with increased wavelength. Another advantage of operating in the thermal-infrared spectrum is that the surfaces of the optical components would not be required to meet the
15   stringent surface quality and accuracy requirements of shorter wavelengths interferometers in order to prevent the generation of surface induced fringes that introduce errors by canceling the interferogram fringes. Thus, if a static interferometer were constructed that could operate in the
20   thermal-infrared, then its optical components would be less costly and less time consuming to manufacture.

Conventional interferometer configurations, such as the Michelson and Sagnac interferometers, utilize beam shearing systems that waste at least 50% of the signal.
25   These configurations typically require the beam of light input into the system to make two passes through a beam splitter during the shearing process. Light is therefore reflected back out the entrance through which it entered,

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resulting in the loss of at least one half of the light entering the static interferometer.

An alternative method that does not rely on the use of a beam splitter to generate a difference in optical path
5   length was described by Padgett et al. U.S. Patent No. 5,781,293. This method involves polarizing the input beam and then shearing it using birefringent crystals. Despite elimination of the beam splitter, at least 50% of the light entering this type of system is lost due to absorption by
10 the input polariser.

A particular advantage of the Padgett et al static interferometer over other conventional interferometers is that it is field widened. Being field widened means that the slit can be increased to any reasonable width without
15 influencing the spectral resolution. An interferometer will be field widened when it records the interferogram at a pupil plane. At a pupil plane, diffraction does not degrade spectral resolution .

A disadvantage of existing static interferometers is
20 that their physical volume and mass increase significantly when high spectral resolution is required. This greatly increases cost in applications such as remote sensing devices mounted on satellites or space exploration vehicles.

25 Another disadvantage is that existing static interferometers do not have a single instrument line shape. The instrument line shape is the characteristic shape of the spectrum generated by the static interferometer when

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the instrument observes a particular frequency of radiation that is substantially narrower in bandwidth than the spectral resolution of the instrument. In existing static interferometers the line shape changes depending on the

5 frequency of the radiation observed. These instruments must be calibrated for the line shape of each frequency in the instrument's bandwidth, which is a time consuming process. Data collected by these static interferometers are difficult to analyze and they are not suitable for

10 generating high spectral resolution output in real time. It is desirable to use a static interferometer that possesses a single instrument line shape and which has near perfect spectral registration. This means that the detector array's output has a single line shape and the lines for the

15 different frequencies are evenly spaced along the spectrum at equal wavenumber intervals. This simplifies the time required to calibrate the instrument and the time required to analyze the data recorded by the instrument.

Accordingly, it is desirable to develop a new static

20 interferometer that is compact, makes use of the majority of incoming radiation, is field widened, can operate in the thermal-infrared region of the spectrum, has a single instrument line shape and has near perfect spectral registration.

25

SUMMARY OF INVENTION

In one aspect, the static interferometer of the present invention is capable of providing an instantaneous

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single-sided interferogram in a tangential exit pupil plane and an image in a sagittal image plane, both of which are located at the same point along the optical axis. The instrument can have an optical efficiency approaching 100

5   percent, has a high signal-to-noise ratio and is field widened. Because the interferogram is generated at a pupil plane by two perfectly collimated beams, the interferogram is not affected by diffraction. This characteristic enables the instrument to possess spectral radiometric

10   purity, have a very broad spectral bandwidth and have the ability to operate within the thermal-infrared spectrum. In addition, this characteristic enables it to have a single instrument line shape and near-perfect spectral registration. Finally, the instrument is a compact and

15   lightweight unit that is easy to align during construction and simple to calibrate.

In one particularly advantageous embodiment, the fore-optics collect light and focus it onto an entrance slit. The light passes through the entrance slit and into the

20   beam shearing system, which splits it into two separate beams. The beam shearing system is constructed to ensure that the two beams of light emerging from it contain more than 50 percent of the collected light that is within the predetermined spectral passband of the instrument. The

25   emerging beams are incident on a Fourier optical system, which collimates and recombines them onto the exit pupil plane. The recombined beams of light generate an interferogram on a detector line array located at a tangential exit pupil plane, enabling the intensity of the

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interferogram to be measured by the detector, read out by electronics and then digitized by an analogue to digital converter. The data processing system then manipulates the digital data to extract useful information concerning the

5   spectral composition of the collected light.   When fore-optics with a shifted pupil are used, measurements can be made using a single sided interferogram at the tangential exit plane. When a Fourier optical system is used that also focuses the light onto a sagiital image plane located at

10 the same point on the optical axis as the tangential exit pupil plane, then a two-dimensional detector array can then be used to record the intensities of both the image and the interferogram.

The forgoing results are preferably achieved by static

15 interferometers having: fore-optics for collecting light and focusing it into a beam; a spectral resolving system comprising of a beam shearing system to split the beam of light having a photon flux within a predetermined spectral passband, an optical system for recombining the two split

20 beams onto an exit pupil, and a detector located at the exit pupil. The beam shearing system preferably includes: an entrance slit structure having an entrance slit extending in a first direction for receiving the light collected by the fore-optics; a beam splitter aligned at an

25 angle to the first direction so that the received beam of light is split into two separate beams; a reflective subsystem having a plurality of reflective surfaces defining separate light paths of equal optical path length for the two separate beams, the reflective surfaces

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arranged such that the two beams contain more than 50 percent of the photon flux that is within the predetermined spectral passband of the collected light. In this embodiment, the chief rays of the two separate beams are 5 also substantially parallel to each other and the two light paths are of substantially equal optical path length.

In one form, the reflective surfaces are also arranged to ensure that the two beams remain substantially in phase relative to one another. In another form, a fore-optics may 10 have a shifted pupil design to generate single-sided interferograms at the exit pupil plane. In yet another form, the optical system has an optical axis and also recombines the beams that emerge from the beam shearing system to create a sagiital image plane located at the same 15 point along that optical axis as the tangential exit pupil plane. In yet another form again, the interferometer contains a detector array, read out electronics and data processing system. The detector array records the intensity of the radiation incident on its pixels, the read out 20 electronics digitizes these measurements and transfers them to the data processing system, and the data processing system manipulates the digitized measurements to obtain information about the spectrum of the incident radiation. In a still further form, the data processing system 25 performs Fast Fourier Transforms (FFTs) on the digitized data to obtain the spectrum of the collected light. In a still further form again, the data processing system convolves the digitized data with digital filters to detect the presence or absence in the spectrum of the collected

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light of frequencies characteristically emitted or absorbed by particular chemicals.

DESCRIPTION OF DRAWINGS

5   The above and other features of the present invention may be more fully understood from the following detailed description, taken together with the accompanying drawings, wherein similar reference characters refer to similar elements throughout and in which:

10   FIGURE 1 is a simplified block diagram of a static interferometer constructed in accordance with one embodiment of the invention;

FIGURE 2 is an optical ray trace diagram of a static interferometer of the type illustrated in FIGURE 1,

15   illustrating the Y-Z plane;

FIGURE 3 is an optical ray trace diagram of a static interferometer of the type illustrated in FIGURE 1, illustrating the X-Z plane;

FIGURE 4 is a three dimensional perspective view of a

20   beam shearing system of the type illustrated in FIGURE 2;

FIGURE 5 is an optical ray trace diagram of a beam shearing system of the type illustrated in FIGURE 2;

FIGURE 6 is an optical ray trace diagram of the rays reflected by the beam splitting surface of a first prism of

25   the beam shearing system of FIGURE 5;

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FIGURE 7 is an optical ray trace diagram of the path of the first split beam in the first and second prisms of the beam shearing system of FIGURE 5;

FIGURE 8 is an optical ray trace diagram of the path
5 of the second split beam in the beam shearing system of FIGURE 5;

FIGURE 8A illustrates the dimensions of the first prism of the beam shearing system of FIGURE 5;

FIGURE 8B illustrates the dimensions of the second and
10 third prisms of the beam shearing structure of FIGURE 5;

FIGURE 9 is an optical ray trace diagram illustrating the path lengths of the two beams sheared by the beam shearing structure of the type illustrated in FIGURE 2;

FIGURE 10 is an optical ray trace diagram illustrating
15 the path lengths of the chief rays of the two beams sheared by the beam shearing structure of the type illustrated in FIGURE 2;

FIGURE 11 is an optical ray trace diagram illustrating the path lengths of the marginal rays of the two beams
20 sheared by the beam shearing structure of the type illustrated in FIGURE 2;

FIGURE 11A is an optical ray trace diagram of an alternative embodiment of the beam shearing system illustrated in FIGURE 1;

25 FIGURE 11B is an optical ray trace diagram of a second alternative embodiment of the beam shearing system illustrated in FIGURE 1;

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FIGURE 12 is an optical ray trace diagram of fore optics of the type illustrated in FIGURE 2;

FIGURE 13 is an optical ray trace diagram of a Fourier optical system of the type illustrated in FIGURE2 (view of

5 the X-Z plane);

FIGURE 14 is an optical ray trace diagram of a Fourier optical system of the type illustrated in FIGURE2 (view of the Y-Z plane);

FIGURE 15 is an optical ray trace diagram of a first

10 alternative embodiment to the Fourier optical system illustrated in FIGURE 1 (view of the X-Z plane);

FIGURE 16 is an optical ray trace diagram of a variation on the first alternative embodiment to the Fourier optical system illustrated in FIGURE 1 (view of the

15 Y-Z plane);

FIGURE 17 is an optical ray trace diagram of a second alternative embodiment to the Fourier optical system illustrated in FIGURE 1 (view of the X-Z plane);

FIGURE 18 is an optical ray trace diagram of a second

20 alternative embodiment to the Fourier optical system illustrated in FIGURE 1 (view of the Y-Z plane);

FIGURE 19 is a three dimensional perspective of a detector array of the type illustrated in FIGURE 1, covered by a blocking filter.

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DETAILED DESCRIPTION OF THE INVENTION

Referring now to the drawings, FIGURE 1 illustrates a static interferometer 10 including fore-optics 12, a beam shearing system 14, a Fourier optical system 16, a detector array 18 and the read out electronics and data processing unit 20. As shown in FIGURES 2 and 3, input light 22 is focused by the fore-optics 12 into a beam 24, which passes through a slit 26 and into the beam shearing system 14. The beam shearing system 14 splits the beam into two separate beams, 30 and 32, that are widely spaced when they emerge. These beams 30,32 enter the Fourier optical system 16, which recombines them to create a pupil plane 34 and an image plane 36. The detector array 18 is located at the pupil plane 34 and at the image plane 36. The detector array 18 measures the intensity of the light incident on different areas within the pupil plane 34 and the image plane 36. These intensity measurements are then recorded by the read out electronics and data processing unit 20, which performs additional manipulations to extract useful information from the raw measurement data.

The static interferometer 10 of FIGURE 1 is preferably fabricated in the configuration shown in FIGURES 2 and 3, with telecentric fore-optics and a telecentric Fourier optical system. This configuration provides spectral radiometric purity, ensures a single instrument line shape, provides perfect spectral registration and ensures that the interferometer is field widened.

   The performance of the static interferometer 10 is
enhanced when the beam shearing system 14 takes the form of
a prism structure 50 as illustrated in FIGURES 4 and 5.
This configuration results in an extremely compact form of
5 the static interferometer 10. The higher the refractive
index of the material used to fabricate the prism structure
50, the more compact the prism's design. The prism
structure 50 also possesses characteristics that eliminate
dispersion and astigmatism, maximize the efficiency of
10 light utilization and ensure the wavefronts of the two
beams emerging from the beam shearing system 30,32 are not
out of phase with respect to each other.

   The prism structure 50 is typically made of KBr to
avoid the need for anti-reflection coatings, but it can
15 also be made from CsI for very broad spectral bandwidth,
from Ge to avoid chromatic defocus and to increase
durability, from ZnSe for high durability. Ge and ZnSe
require the use of anti-reflective coatings and the
performance of CsI is considerably enhanced if
20 antireflective coatings are used. In the illustrated
embodiment, all prisms in the prism structure 50 are made
from the same material to ensure that both the beams
emerging from the beam shearing system 30,32 travel through
optical paths of identical length.

25   Considering the prism structure 50 of FIGURE 4 in
further detail, the first prism 52 consists of an entrance
surface 54 and a beam splitting surface 56. A portion of
the entrance surface 54 is covered in a reflective coating

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58 and a portion of the beam splitter surface 54 is covered in a beam splitter coating 60. The second prism 62 and third prisms 66 each have a surface that is completely coated in a reflective coating 64 and 66. All other

5 surfaces in the prism are optically transparent. The reflective coatings of the prism structure 50 are typically made from Al, Au or Ag and the beam splitter coating 60 is usually made from Ge.

The material chosen to construct the prism structure

10 illustrated in FIGURE 4 effects the optical efficiency of the beam splitter. The variation in optical efficiency with the choice of material is demonstrated by TABLE 1A.

TABLE 1A.   PRISM EFFICIENCIES AT 10 μm WAVELENGTH.

Substrate/Coating	Ge + Al [1]	Ge + Al + Protective [2]	Ge + Au + AR [3]
KBr	80 %	85 %	95 %
CsI	72 %	80 %	95 %
ZnSe	-	-	91 %
Ge	-	-	90 %

NOTE 1:   "Ge + Al" implies a germanium beam splitter plus

15 aluminum coatings on all reflection surfaces.   No coatings are placed on transmission surfaces.

NOTE 2:   "Ge + Al + Protective" implies a germanium beam splitter coating, aluminum reflection coatings, and protective coatings on all transmission surfaces.   The

20 protective coatings protect the water-soluble salt crystals from moisture.

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NOTE 3:   "Ge + Au + Ar" implies a germanium beam splitter coating, gold reflection coatings, and anti-reflection coatings on transmission surfaces.   The gold coatings require an adhesive layer.   No germanium beam splitter coating is required for the germanium substrate.   The AR coatings on the salt crystals are assumed to be narrow-band, and the AR coatings on the metallic substrates are assumed to be broad-band.

A closer examination of FIGURE 5 demonstrates how the prism structure 50 shears the input beam 70 of FIGURE 5 into two separate beams 72 and 74. The input beam 70 enters the prism through the entrance surface 54 and is incident upon the beam splitter coating 60. This splits the beam and approximately 50% of the light is reflected in a first split beam 72 and the remainder of the light is transmitted in a second split beam 74. It is advantageous for the prism structure to be manufactured with the beam splitting surface 56 having a minimal tilt relative to the entrance surface 54, shown as π on FIGURE 5. This improves the efficiency of the beam splitting coating 60, reduces polarization and prevents the first split beam 72 from being totally internally reflected at the air gap between the beam splitter surface 56 and the second prism 62 by the beam reflected off the reflective coating on the entrance surface 58.

The first split beam 72 is reflected by the reflective coating on the entrance surface 58 and is then reflected again by the second prism's reflective surface 64. The

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first split beam 72 then exits the prism structure 50 through the exit surface 76. The second split beam 74 continues until it strikes the third prism's reflective surface 68, where it is reflected and exits the prism structure 50 through the exit surface 76. The surfaces of the prism structure are arranged so that the first split beam of light 72 and the second split beam of light 74 have traveled the same optical distance and are parallel when they exit the exit surface 76. Overall, the prism structure 50 is extremely efficient in its utilization of light. The only way that light entering the system through the entrance surface 54 can exit the prism structure 50 is through the exit surface 76.

The prism structure 50 reflects the first split beam 72 three .times and the second split beam 74 only once ensure that the wavefronts of the two beams do not undergo a 180° phase change with respect to each other. If the two wavefronts are in-phase, then the image is preserved across the entrance slit 26, single sided interferograms can be generated without loss of signal, and the optical aberrations generated by the Fourier optical system 14 tend to cancel out when the two beams 30,32 recombine at the detector array 18.

The shape of the prism structure 50, as shown in FIGURE 4, affords easy mounting and alignment. Proper alignment of the prisms is important because it ensures that the modulation efficiency of the interferometer is maximized. The modulation efficiency is a measure of the

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fringe visibility or contrast and directly affects the signal amplitude. When the chief rays emerging from the prism are not parallel to each other or the optical system is not telecentric, then the modulation efficiency, $\eta(\beta)$,

5   decreases as a function of the angle, β, between the two chief rays:

$$\eta(\beta) = \frac{\sin(\pi v \Delta S \sin \beta)}{\pi v \Delta S \sin \beta}$$

where

   ΔS is shown on FIGURE 5,

10   and

   $v = 1/\lambda$ is the wavenumber frequency for a given
   .   wavelength.

Therefore, a special mounting system (not shown) manufactured from aluminum is used that hard mounts the

15   prisms 52,62,66 without the need for epoxies. The prisms are held in aluminum caps that are held in place by springs. The springs hold the prisms in alignment when the spectrometer temperature is reduced. The air gaps between the prisms are not sealed with adhesives because this

20   introduces strong absorption features in the thermal infrared region of the spectrum.

A closer examination of FIGURES 5 through 11 reveals how the prism structure 50 is manufactured to ensure that it possesses the properties necessary for it to function

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effectively as the beam shearing system 14 in the static interferometer 10. Three requirements apply to the construction of all of the three prisms 52,62,66. The first is that the prism structure is constructed so that the

5   entrance surface 54 is substantially perpendicular to the chief ray of the input beam 78 and the exit surface 76 is substantially perpendicular to both chief rays of the exit beams 30 and 32. The purpose of constructing the prism structure 50 in this way is to eliminate dispersion and

10   astigmatism. Dispersion alters the instrument line shape as a function of wavenumber and astigmatism creates different wavefront errors in each of the two exit beams 30 and 32, broadening the instrument line shape. The following equation and explanation illustrates the effect of

15   astigmatism on the instrument line shape. Let $\Delta \varepsilon$ represent the difference in wavefront errors between the two beams at the exit pupil. Wavefront errors are caused by optical aberrations. If the optical aberrations or wavefront errors of the two beams are identical and vary slowly across the

20   wavefront, then there is no influence on the spectral resolution or instrument line shape. Astigmatism would cause a difference in wavefront errors between the two beams. For a given $\Delta \varepsilon$, the width of the instrument line shape at half maximum, $\Delta v_{\frac{1}{2}}$, will increase according to the

25   following equation:

$$\Delta v_{1/2} = \frac{0.605}{\delta_{max}} + \frac{1}{y_{max}} \sqrt{\frac{v \Delta \varepsilon}{2 \cos\left(\frac{FOV_F}{2}\right)} \left\{ \left[\frac{F}{\Delta S \cos\left(\frac{FOV_F}{2}\right)}\right]^2 - \frac{1}{4} \right\}}$$

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where

ΔS is shown on FIGURE 5

F is the focal length of the Fourier Lens,

δ_{max} is the maximum optical path difference,

5   y_{max} is the distance between the center of the exit pupil and the edge of the exit pupil,

and

$FOV_F = 2 \; arctan(\Delta S \; / \; 2F)$ is the field of view of the Fourier Lens.

10   The second is that the breadth of each of the prisms 52,52,66, shown as b_P on FIGURE 4, must be large enough so that all the light entering through the length of the slit is contained within the prism. In addition to these two requirements, there are manufacturing requirements that 15 apply to each of the prisms 52,62,66 individually. The third is that the entrance surface must be perpendicular to the exit surface to minimize optical aberrations.

A closer examination of FIGURE 6 demonstrates that the first prism 52 is manufactured so that its shape ensures 20 the following. Firstly, the portion of the entrance surface 54 that is not coated is large enough to ensure that none of the input beam 70 is incident upon the portion of the entrance surface that is coated in reflective coating 58. Secondly, the portion of the beam splitting surface that is 25 coated in a reflective coating 60 is wide enough to ensure that none of the input beam 70 is incident on the portion

of the beam splitting surface 56 that is not coated in beam splitting coating. Thirdly, the width of the first prism w_1, the height of the first prism, shown as h_1 on FIGURE 6 and the tilt angle of the beam splitting surface relative to

5 the entrance surface, shown as π on FIGURE 6, ensure that the entire first split beam 72 is incident on the portion of the entrance surface 54 that is coated in reflective coating. Fourthly, the width of the first prism w_1, the height of the first prism h_1, the tilt angle π and the

10 length of the beam splitting surface 56, shown as l_1 on FIGURE 6, ensure that the entire beam 80 reflected from the portion of the entrance surface coated in reflective coating is incident on the portion of the beam splitting surface 56 that is not coated in beam splitting coating.

15 Finally, the width of the first prism w_1, the height of the first prism h_1, the tilt angle π and the length of the beam splitting surface l_1 ensure that the length of the optical paths taken by the first split beam 72 and the second split beam 74 throughout the entire prism structure 50 are

20 equivalent.

A closer examination of FIGURES 7 and 8 reveals that the second prism 62 is manufactured so that its shape ensures the following. Firstly, that the surface of the second prism adjacent to the beam splitting surface of the

25 first prism 56 is matched to that surface. Secondly, that the width of the second prism, shown as w_2 on FIGURE 7 and the angle of the second prism's reflective surface 64 relative to the entrance surface 54, shown as θ on FIGURE 7

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ensure that the entire beam 80 reflected from the portion
of the entrance surface coated in reflective coating is
incident upon the second prism's reflective surface 64 and
that the chief ray of the beam of light reflected from this
5   surface 82 is perpendicular to the second prism's exit
surface 84. Thirdly, the width of the second prism w_2, the
angle of the second prism's reflective surface relative to
the entrance surface θ and the height of the surface of the
second prism that is adjacent to the third prism 86, shown
10 as h_2 on FIGURE 7, ensure that the entire beam reflected
from the second prism's reflective surface 88 emerges from
the exit surface of the second prism 84 and that none of
second split beam 74 is incident on the second prism's
reflective surface 64. Fourthly, the angle between the
15 surface of the second prism adjacent to the third prism 86
and the second prism's exit surface 84, shown as ϕ in FIGURE
7, is as close to 90° as possible to prevent any total
internal reflection that may result due to the tiny air gap
between the two prisms. Finally, the width of the second
20 prism w_2, the angle of the second prism's reflective surface
relative to the entrance surface θ and the height of the
surface of the second prism adjacent to the third prism h_2
ensure that the length of the optical paths taken by the
first split beam 72 and the second split beam 74 throughout
25 the entire prism structure 50 are equivalent.

A closer examination of FIGURE 8 reveals that the
third prism 66 is manufactured so that its shape ensures
the following. Firstly, the surfaces of prisms two 62 and

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three 66 that are adjacent to each other 86 and 90 are matched to eliminate dispersion and aberration. Secondly, that its height, shown as h_3 on FIGURE 8, its width, shown as w_3 on FIGURE 8 and the angle of its reflective surface 68

5 relative to the entrance surface 54, shown as α on FIGURE 8, ensure that the chief ray of the beam of light reflected from the third prism's reflective surface 92 is perpendicular to the third prism's exit surface 94 and that the entire beam of light reflected from the third prism's

10 reflective surface 96 exits the third prism through the third prism's exit surface 94. Finally, that the third prism's height h_3, width w_3 and the angle of its reflective surface relative to the entrance surface α ensure that the length of the optical paths taken by the first split beam

15 72 and the second split beam 74 throughout the entire prism structure 50 are equivalent. FIGURES 8A and 8B show the dimensions of a prism structure 50 manufactured to receive an F/4 input beam from a slit with a length of 12.8mm. FIGURE 8A shows the dimensions of prism one 52 and FIGURE

20 8B shows the dimensions of prisms two and three 62,68. An optical prescription for these prisms is contained in TABLES 1B – 1D for an optical system presented in TABLE 2. The description of the tables is presented in the form utilized by the optical design program marketed under the

25 tradename ZEMAX.

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TABLE 1B.   Non-Sequential Components Parameters

Obj Type	Obj Name	Y Position	Z Position	Tilt X	Material	X ½ Width	Y ½ Width
Poly Obj	Prism A				KBr	Scale 1	Is Vol 1
Poly Obj	Prism B		5.851		KBr	Scale 1	Is Vol 1
Poly Obj	Prism C		21.851		KBr	Scale 1	Is Vol 1
Rectangle	A1 Mirror	4.15	-0.01	10	Mirror	16	5.85
Rectangle	A2 BmSp	-5.40	6.65	-45	mirror/KBr	16	4.64
Rectangle	C2 Mirror		37.0		Mirror	16	14

TABLE 1C.   Prism A Vertex Parameters

Front Face Vertices				Back Face Vertices			
V 1	-16	-10	0	V 5	-16	-10	5.85
V 2	-16	10	0	V 6	-16	10	9.38
V 3	16	10	0	V 7	16	10	9.38
V 4	16	-10	0	V 8	16	-10	5.85
Repeated Vertices							
Front R 1 2 3 4 0				Back R 5 6 7 8 0			
Top R 2 6 7 3 0				Bottom R 1 5 8 4 0			
Left side R 1 2 6 5 0				Right side R 4 3 7 8 0			

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TABLE 1D.   Prism B Vertex Parameters

Front Face Vertices				Back Face Vertices			
V 1	-16	-10	0	V 5	-16	-10	16
V 2	-16	10.00357	3.53	V 6	-16	1.27	16
V 3	16	10.00357	3.53	V 7	16	1.27	16
V 4	16	-10	0	V 8	16	-10	16
Repeated Vertices							
Front R 1 2 3 4 0				Back R 5 6 7 8 0			
Top R 2 6 7 3 0				Bottom R 1 5 8 4 0			
Left side R 1 2 6 5 0				Right side R 4 3 7 8 0			

TABLE 1E.   Prism C Vertex Parameters

Front Face Vertices				Back Face Vertices			
V 1	-16	-10	0	V 5	-16	-10	25.15
V 2	-16	10	0	V 6	-16	10	5.15
V 3	16	10	0	V 7	16	10	5.15
V 4	16	-10	0	V 8	16	-10	25.15
Repeated Vertices							
Front R 1 2 3 4 0				Back R 5 6 7 8 0			
Top R 2 6 7 3 0				Bottom R 1 5 8 4 0			
Left side R 1 2 6 5 0				Right side R 4 3 7 8 0			

5   A requirement in the manufacture of all the prisms, is
that they must ensure the length of the optical paths taken

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by the first split beam 72 and the second split beam 74 through the prism structure 50 are equivalent. This requirement means that each of the rays in the split beams of light 72,74 must travel the same distance in each of the

5   materials present in the prism structure 50 as the corresponding ray in the other split beam of light. A closer examination of FIGURES 9, 10 and 11 demonstrates that the prism structure 50 ensures that this occurs. In each of these figures the optical distance of the ray of

10 the first split beam of light is the sum of the three distances d_1, d_2 and d_3 and the optical distance traveled by the corresponding ray of the second split beam of light is the sum of the two distances d_4 and d_5. In each of FIGURES 9, 10 and 11, $d_1 + d_2 + d_3 = d_4 + d_5$. Minor variations in the

15 width of the air gaps between prisms one and two and prisms two and three are inconsequential. The optical path length for the prism structure shown in FIGURES 8A and 8B is 47mm and the width of the air gaps is approximately 10 microns. This difference is unimportant because it does not have a

20 significant effect on the marginal ray angles of the two split beams 72,74, when they are incident on the Fourier optical system 16.

A variation on the embodiment of the beam shearing system 14' described above is shown in FIGURE 11A, this

25 arrangement replaces the prism structure 50 with an structure involving parallel plates acting as a beam splitter 150 and three mirrors 152, 154 and 156. The basic arrangement of 3 reflections for the first split beam 72' and one reflection for the second split beam 74' is

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maintained. Use of this beam shearing system 14' places a limitation on the F/# of the input beam and the possible size of the separation between the two emerging beams 30' and 32', shown as Δs on FIGURE 11A because the beams

5 diverge more rapidly in air than in a higher index material.

A closer examination of FIGURE 11A reveals that the static interferometer must be manufactured in the following way. The entrance slit 26' must be mounted inside the first

10 mirror 152 and the parallel plate beam splitter 150 oriented perpendicular to the chief ray of the entrance beam 158. The parallel plate beam splitter is coated on the second surface of the first parallel plate, and the second parallel plate is of equal thickness to the first plate to

15 ensure that the total optical path length traveled by both beams is equal.

The first mirror is tilted at an angle that ensures that the first split beam 72' is reflected from the beam splitter 150 to the second mirror 154. The slit must be

20 small compared to the returning beam 72' to minimize the amount of light lost. The second and third mirrors are aligned so that the chief rays of the two emerging beams 30' and 32' are parallel. Overall, the mirrors must be arranged to ensure that both split beams of light 72',74'

25 travel the same optical distance.

Another variation of the beam shearing system is shown as 14'' in FIGURE 11B. This variation is designed for use with a collimated input beam. It uses a similar parallel

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plate and mirror configuration as in FIGURE 11A except that the beam splitter 150' is tilted with respect to the input beam 70'. The beam splitter 150' splits the input beam into two beams 72'' and 74''. These beams are then reflected in

5   a similar fashion to the beam shearing system shown as 14' in FIGURE 11A. However, because the beams are collimated, the beam shearing system 14'' is able to recombine the two split beams at an exit pupil plane without the need for the Fourier optical system. The beam shearing system places a

10 limitation on the F/# of the fore-optics to ensure that the exit pupil is sufficiently far from the fore-optics to enable the configuration shown.

The best performance of the static interferometer 10 is achieved, when the fore-optics are as shown in FIGURE

15 12. Manufacturing the fore-optics in this way ensures that the pupil of the fore-optics is shifted to one side of the optical axis. This results in the chief ray of the input beam 22 striking the exit pupil 34 at the edge of the detector array 18, enabling a single sided interferogram to

20 be recorded. Using a single sided interferogram instead of a complete interferogram reduces the size of the other components of the static interferometer 10 by a factor of two, without losing any information or signal.

Examining the illustration in FIGURE 12 in greater

25 detail, reveals that the fore-optics 12 comprise a scan mirror 160 and three coaxial aspheric mirrors 162, 164 and 166. The first coaxial aspheric mirror 162 is an even asphere and the other two mirrors are simple conics 164,

166. The input beam 22 is reflected by the scan mirror onto the first coaxial asphere 162, which reflects the light onto the second coaxial asphere 164. The light is finally reflected by the third coaxial asphere 166, which

5 focuses the light onto the entrance slit 26. The focused beam 168 is telecentric and it is observed that its chief ray strikes one side of the aperture stop 170 of the second coaxial aspheric mirror because the pupil of the fore-optics is shifted. The four mirrors 160, 162, 164, 166 are

10 co-axial, which means that the fore-optics are simple to construct.

A specific example of the mirror configuration of the fore-optics 12, illustrated in FIGURE 12, is provided in part of TABLE 2. The description of TABLE 2 is presented in

15 the form utilized by the optical design program marketed under the tradename ZEMAX. The prescription in TABLE 2 assumes that the output light 24 is F/4 in the tangential y-plane and F/5 in the sagiital X-plane.

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TABLE 2. ZEMAX PRESCRIPTION: Telescope and Prism in

1.2 cm^{-1} Imaging Spectrometer.

Surface	Type	Name	Radius	Thickness	Conic	Coeff on r 4	Coeff on r 6	Coeff on r 8
			Mm	mm				
Object			Infinity	infinity				
1	apert	ent port		130				
2	coord	tilt Y				6°		
3	mirror	Scan	Infinity	-140				
4	coord	tilt Y				6°		
5	mirror	TM1 asph	631.6257	122.6101	-3.2	-8.326e-10	3.06657e-14	-2.45337e-18
STOP	mirror	TM2 conic	176.0148	-122.6101	0.155589			
7	mirror	TM3 conic	244.9272	215.1279	0.182058			
8	coord	Decenter Y				31.2483 mm		
9	apert	Slit		3				
10	coord	Decenter Y				3.2 mm		
11	NSC	Prism			Reverse rays: 1	exit location Y: -10.001 mm	exit location Z: 16.1112 mm	exit tilt X: -90°
12	standrd	Gap		-0.042				
13	coord	Decenter Y				-12 mm		
14	coord	tilt Y		-134.468		-13.383°		
15	coord	Decenter X				13.927 mm		
16	mirror	X toroid FM1	136.1947 148.5778	113.6148		-9.0040886e-9	-2.775225e-13	
17	mirror	X toroid FM2	-74.663 99.7735	-77.3079		5.3235734e-6	-2.8462433e-7	-8.10146e-10
18	mirror	asphere FM3	171.811	77.3079		-9.2187783e-8	1.719915e-11	-2.72977e-15
19	mirror	Y toroid FM4	-298.0 -209.474	-132.6079		7.7831648e-8	-1.816862e-11	
20	coord	tilt Y				14.582°		
Image		focal plane	infinity					

NOTE 1: Spectral resolution is 1.21 cm^{-1}. Pupil width is 50 mm, X-Field is +/- 1.888°, Y-Field is 9°, and wavelength is

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13 µm.   Design is valid between 5 and 20 µm with KBr or 5
and 50 µm with CsI.   Tangential width of stop is 30.6 mm;
sagittal width is 24.6 mm.   Stop is shifted along
tangential plane away from slit so that chief ray is 6.2 mm
5   from short side and 23.8 mm from long side of stop.
Detector is 12.8 x 16 mm.

NOTE 2: In Zemax the X toroids are generated by placing
coordinate breaks of 90° and -90° before and after a
10   standard "Y" toroid.   However, many optical design packages
explicitly call out Y and X toroids   to omit the two
coordinate breaks.   Therefore the coordinate breaks for the
X toroids have been omitted in the above prescription.   The
top number is the radius, and the bottom number is the
15   radius of rotation.

NOTE 3: Decenters, tilts, and NSC parameters are listed in
the columns with the headings "Conic",   "Coeff. on r4",
"Coeff. on r6", and "Coeff. on r8".

20   The best performance of the static interferometer 10
is achieved, when the two beams emerging from the beam
shearing system 30,32 are recombined using the Fourier
optical system 16 shown in FIGURES 13 and 14. The Fourier
optical system 16 is manufactured to maximize the image
25   focal length and spatial resolution of the Fourier optical
system by ensuring that the imaging and collimating
functions are performed by the same optical components.   It
is also telecentric in the tangential plane to ensure
spectral radiometric purity.

30   Examining the illustration in FIGURES 13 and 14 in
greater detail, it shows a form of the Fourier optical
system 16 having four mirrors and which is completely
anamorphic.   The first and second mirrors 180,182 are

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aspheric toroids that each have an aspherical surface in the X plane and a spherical surface in the Y plane. The third mirror 184 is an even asphere and the fourth mirror 186 is an aspheric toriod with an aspheric surface in the Y

5   plane and a spherical surface in the X plane. All four mirrors are co-axial, with a vertices along the common axis 190. This property ensures that no alignment of the mirrors of the Fourier optical system is required. Their mounting (not shown) is a simple 'bolt and go' configuration.

10   The mirrors are manufactured to ensure that the two beams emerging from the beam shearing system 30,32 strike the first mirror 180 and are reflected onto the second mirror 182, which is located inside a cut out of the fourth mirror 186. The mirrors also ensure that the two beams are

15   then reflected onto the third mirror 184 and from there onto the fourth mirror 186. The combination of the four mirrors ensures that the light reflected from the fourth mirror 186 forms two collimated exit beams 192 and 194 that exit the Fourier optical system through a cut-out of the

20   third mirror 184. The manufacture of the mirrors ensures that the two exit beams 192,194 combine and form a pupil plane 34 in the Y plane and an image plane 36 in the X plane, with both planes located at the same point along the optical axis 190.

25   A specific example of the mirror configuration of the Fourier optical system 16, illustrated in FIGURE 13 and 14, is also provided in TABLE 4. The description of TABLE 3 is presented in the form utilized by the optical design

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program marketed under the tradename ZEMAX. Manufacturing the Fourier optical system 16 according to the prescription in TABLE 4 results in it having focal length in the X and Y plane of 64mm.

5   Manufacturing the fore-optics 12, the beam shearing system 14 and the Fourier optical system 16 according to the prescriptions contained in TABLES 1B - 1E and 2, results in the static interferometer achieving a spectral resolution of $1.2cm^{-1}$ over the spectral bandpass of the
10   material used to construct the prism structure 50. If the length of the entrance slit 26 is chosen to be 12.8 mm, then the static interferometer 10 will have a 3.8° field of view (FOV).

      An alternative method of manufacturing the Fourier
15   optical system 16' to achieve a broadband, high spectral resolution, off-axis point spectrometer is shown in FIGURE 15. It consists of four off-axis aspheres, 180', 182', 184' and 186', which generate two very high quality collimated beams. These beams generate a 0.5 cm^{-1}, single-sided
20   interferogram across a 25mm detector array.

      FIGURE 16 shows a variation on this alternative method of manufacturing the Fourier optical system 16''. This variation uses the same four off-axis aspheres, 180'', 182'', 184'' and 186'', but uses a fold mirror 200 and a
25   cylindrical mirror 202 to compress the collimated beam to 1mm in the X direction to improve the signal efficiency and reduce the width of the detector array 18. A cylindrical mirror 202 is preferable to a refractive cylindrical lens

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because the rays of the collimated beams passing through the thicker part of a lens would be shifted in the Y direction with respect to the rays passing through the thinner part of that lens. An optical prescription for this
5 Fourier optical system 16'' is contained in TABLE 2.

TABLE 3.   ZEMAX PRESCRIPTION: 0.5 cm^{-1} Point Spectrometer

Surface	Type	Name	Radius	Thickness	Coeff on r 4	Coeff on r 6
			mm	mm		
Object			infinity	infinity		
STOP	standrd	ent pupil		100		
2	paraxial	telescope	100	100		
3	apert	slit		3		
4	KBr	prism		93		
5	coord	tilt X			-45°	
6	mirror	C2				
7	coord	tilt X		-15	-45°	
8	standrd	prism exit				
9	coord	decenter Y			-27.75 mm	
10	coord	tilt Y		-138.7318	-4.6515°	
11	coord	decenter X			±13.5551 mm	
12	mirror	M1 asphere	146.0153	83.9595	1.5855e-9	-4.1844e-14
13	mirror	M2 asphere	109.167	-95.2057	4.1951e-7	-8.3999e-10
14	mirror	M3 asphere	235.8198	95.2057	4.1801e-8	-1.0609e-13
15	mirror	M4 asphere	-295	-120.4057	4.3190e-8	2.7327e-12
16	coord	dec X tilt Y			12.1 mm	4.6515°
17	coord	tilt Y			20°	
18	mirror	fold mirror				
19	coord	tilt Y		26.12	20°	
20	coord				-20°	
21	mirror	X toroid	-56			
22	coord			-26	-20°	
Image		focal plane	infinity			

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NOTE 1:   Spectrometer can achieve 0.5 cm^{-1}.   Pupil width is 50 mm, X,Y-Fields are +/- 0.55° and wavelength is 13 μm. Design is valid between 5 and 20 μm with KBr or 5 and 50 μm with CsI.   Tangential width of stop is 25 mm; sagittal

5   width is 12.5 mm.   Stop is shifted along tangential plane by - 9.3 mm.   A paraxial lens is used to simulate the telescope.   Shifts in the ± X direction simulate the prism. Cylindrical   mirror   compresses   beam   without   adversely affecting interferogram.   Detector array is 1 x 25 mm

10

NOTE 2: Decenters and tilts are listed in the column with the heading "Coeff. on r4".

An   alternative   method   of   manufacturing   the   Fourier optical   system   16′′′   to   achieve   a   large   FOV,   on-axis

15   refractive imaging spectrometer is shown in FIGURES 17 and 18.   This   configuration   is   appropriate   where   the   spectral bandwidth requirements are not too broad. The imaging focal length   can   be   made   significantly   shorter   than   the interferogram focal length of the Fourier optical system

20   16′′′ to increase the FOV. The design, shown in FIGURES 17 and 18, uses three aspheric Ge lenses 210, 212 and 214 to collimate the beams emerging from the beam shearing system 30,32 to form a pupil plane 34 in one axis and to form an image plane 36 in the other axis. An optical prescription

25   for this Fourier optical system 16′′′ is contained in TABLE 4.

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TABLE 4. ZEMAX PRESCRIPTION: 1.2 cm^{-1} On-Axis Imaging Spectrometer

Surface	Type	Name	Radius	Thickness	Coeff on r 4	Coeff on r 6	Coeff on r 8
			mm	mm			
Object			infinity	infinity			
STOP	standrd	ent pupil		64			
2	paraxial	Telescope	64	64			
3	apert	Slit		3			
4	KBr	Prism		40.158			
5	coord	tilt X			-45°		
6	mirror	C2					
7	coord	tilt X		-6.842	-45°		
8	standrd	prism exit		21.2106			
9	Ge	L1 asphere	292.1871	3	-3.1404e-7	-4.477e-11	-4.1884e-13
10	-	**Y** toroid	-285.5098	14.5723			
11	Ge	L2 standard	67.2090	2.35			
12	-	asphere	-60.0	38	-1.0316e-7	1.76843e-11	-3.6181e-11
18	Ge	L3 window	infinity	1.5			
21		**Y** toroid	-63.6822	15	-1.1044e-5	1.78802e-7	
Image		focal plane	infinity				
Surface	Type	Name	Radius	Thickness	Coeff on r 4	Coeff on r 6	Coeff on r 8
			mm	mm			
Object			infinity	infinity			
STOP	standrd	ent pupil		64			
2	paraxial	telescope	64	64			
3	apert	slit		3			
4	KBr	prism		40.158			
5	coord	tilt X			-45°		
6	mirror	C2					
7	coord	tilt X		-6.842	-45°		
8	standrd	prism exit		21.2106			
9	Ge	L1 asphere	292.1871	3	-3.1404e-7	-4.477e-11	-4.1884e-13
10	-	**Y** toroid	-285.5098	14.5723			

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Surface	Type	Name	Radius	Thickness	Coeff on r 4	Coeff on r 6	Coeff on r 8
			mm	mm			
11	Ge	L2 standard	67.2090	2.35			
12	-	asphere	-60.0	38	-1.0316e-7	1.76843e-11	-3.6181e-11
18	Ge	L3 window	infinity	1.5			
21		**Y** toroid	-63.6822	15	-1.1044e-5	1.78802e-7	
Image		focal plane	infinity				

NOTE 1: Pupil width is 16 mm, Y-Fields are +/- 12° and wavelength is 13 μm. Design is valid between 5 and 16 μm. Width of stop in X direction is 16 mm. Width in Y direction is 12.8 mm. Stop can be shifted along tangential plane to generate single-sided interferogram and achieve 1.2 cm^{-1} spectral resolution. A paraxial lens is used to simulate the telescope. Coordinate break shifts in ± X simulate the prism. Detector array is 12.8 x 16 mm.

NOTE 2: In this design the pupil plane is in the X direction and the image plane is in the Y direction. This enabled "Y" toroids to be used to generate the image, and "Y" toroids do not require coordinate brakes to rotate them about the Z axis.

NOTE 3: Tilts are listed in the column with the heading "Coeff. on r4".

Closer inspection of FIGURE 2 illustrates that a 2 dimensional detector array is located at the pupil 34 and image 36 planes. This array makes measurements of light intensity in both the pupil and image planes. Large format AlGaAs Quantum Well Infrared Photoconductor (QWIP) arrays

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are the most appropriate detectors because their pixel to pixel responsivity is uniform. AlGaAs QWIP arrays can be fabricated with an operability greater than 99.99%, an uncalibrated uniformity better than 2% and a calibrated

5 uniformity better than 0.3%. They can also be thermally cycled indefinitely, are radiation hard and remain stable after calibration.

AlGaAs QWIP detector arrays are not the only type of detector that can be used. Other examples of detector

10 arrays that could be utilized by the static interferometer 10 include InSb, HgCdTe, microbolometers, thermopiles, CCDs and active pixel sensor (APS) arrays.

The processor unit 20 analyzes the data recorded by the detector array 18. This unit digitizes the data, stores

15 it, can analyze it in a number of ways, including the two following methods and can output any results. The data recorded by the detector array 18 corresponds to a series of interferograms. The first possible method of analyzing this data is to perform a digital fast fourier transform

20 (FFT) to convert each interferogram into a spectrum, which can then be further analyzed. An example would be where the spectrum is analyzed to determine the overall chemical composition of the scene being viewed.

An alternative method of analyzing the data is to use

25 the interferograms as matched filters to detect distinct features within the interferograms. An example of this would be to detect the presence of a single chemical in the scene being viewed. This process involves using a filter

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shape that indicates the presence or absence of that feature, when the filter is convolved with the interferogram. An advantage of using this second technique is that it is less computationally intensive than

5 performing numerous FFTs. Another advantage is that the interferogram automatically separates broadband features, such as emisssions from a planet's surface from narrowband features, such as are created by constituent gases in the planet's atmosphere.

10 At shorter wavelengths it may be necessary to use heterodyning at the detector array. Heterodyning is appropriate if a full cycle of the interferogram 220 of FIGURE 19 is located inside one pixel 222 of the detector array 18. When this occurs, the constructive 224 and

15 destructive 226 half cycles of the interferogram will cancel each other out and the detector 18 will detect zero light intensity for that pixel 222. This phenomenon can be avoided by using a blocking filter 228. This filter discards the destructive portion of the interferogram 226,

20 ensuring that only the constructive portion of the interferogram 224 is incident on the pixel of the detector array 222. In a broadband system, the blocking filter must be manufactured so that its pattern has a frequency that is equal to or lower than the lowest frequency in the

25 predetermined spectral passband. The detector will then detect that light to be frequency zero and light with higher frequency will be detected as having a frequency equal to the actual frequency of the detected radiation minus the frequency of the radiation of lowest frequency.

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In this way a spectrum is able to be constructed from the interferogram 220, using a detector 18 that would not have enough pixels to measure the intensity of the interferogram without the use of a blocking filter.

5   While the preferred embodiment has been described and illustrated, various substitutions and modifications may be made thereto without departing from the scope of the invention. Accordingly, it is to be understood that the present invention has been described by way of illustration

10   and not limitation.

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CLAIMS

1 1. A beam shearing system comprising:

2   an entrance slit structure having an entrance
3 slit extending in a first direction for receiving a
4 beam of light having a photon flux within a
5 predetermined spectral pass band;

6   a beam splitter aligned at an angle to the first
7 direction so that the received beam of light is split
8 into two separate beams; and

9   a reflective subsystem having a plurality of
10 reflective surfaces defining separate light paths of
11 equal optical path length for the two separate beams,
12 the reflective surfaces arranged such that when the
13 two beams emerge from the beam shearing system they
14 contain more than 50 percent of the said photon flux
15 and the chief rays of the two separate beams are
16 substantially parallel to each other.

1 2. The beam shearing system in claim 1 wherein:

2   said two beams emerging from the beam shearing
3 system contain substantially all of the light entering
4 the system through the entrance slit.

1 3. The beam shearing system in claim 1 wherein:

2   said two light paths being of substantially equal
3 optical path length and causing the wave fronts of the

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1 two separate beams to remain substantially in phase
2 relative to one another.

1 4. The beam shearing system in claim 1 wherein:

2   said plurality of reflective surfaces are further
3 arranged so that the separate beams of light are of
4 substantially equal intensity, when they emerge from
5 the beam shearing system.

1 5. The beam shearing system in claim 1 wherein:

2   the reflective subsystem comprises a plurality of
3 bodies with a beam splitter therebetween; and

4   the entrance and exit surfaces of the plurality
5 of bodies are substantially perpendicular to the chief
6 ray of the received beam of light.

1 6. A spectral resolving system comprising:

2   an entrance slit structure having an entrance
3 slit extending in a first direction for receiving a
4 beam of light having a photon flux within a
5 predetermined spectral pass band;

6   a beam shearing system including:

7   a beam splitter aligned at an angle to the
8   first direction so that the received beam of
9   light is split into two separate beams;

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a reflective subsystem having a plurality of reflective surfaces defining separate light paths of equal optical path length for the two separate beams, the reflective surfaces arranged such that when the two beams emerge from the beam shearing system they contain more than 50 percent of the said photon flux and the chief rays of the two separate beams are substantially parallel to each other; and

an optical system focusing the said two separate beams of light emerging from the said beam shearing system onto an exit pupil.

7. The spectral resolving system of claim 6 wherein:

said optical system also focuses the said separate beams of light emerging from the said beam shearing system to create an image.

8. The spectral resolving system of claim 7 wherein:

said optical system has an optical axis;

said exit pupil is located in one of the group consisting of a tangential plane and a sagiital plane relative to the said beam shearing system;

said image is located in the other of the group consisting of a tangential plane and a sagiital plane relative to the said beam shearing system; and

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1   the exit pupil and the image are located at

2   substantially the same position along the optical

3   axis.

1   9.   The spectral resolving system of claim 6 wherein:

2   the optical system is telecentric in the said

3   exit pupil plane.

1 10. The spectral resolving system of claim 6 wherein:

2   the optical system is anamorphic.

1 11. The spectral resolving system of claim 6 wherein:

2   the said optical system cancels aberrations when

3   it recombines the two beams of light that emerge from

4   the beam shearing system.

1 12. A static interferometer comprising:

2   fore-optics for collecting light and focusing it

3   into a beam;

4   a spectral resolving system comprising:

5   an entrance slit structure having an

6   entrance slit extending in a first direction for

7   receiving a beam of light having a photon flux

8   within a predetermined spectral pass band;

9   a beam shearing system including:

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a beam splitter aligned at an angle to the first direction so that the received beam of light is split into two separate beams;

a reflective subsystem having a plurality of reflective surfaces defining separate light paths of equal optical path length for the two separate beams, the reflective surfaces arranged such that when the two beams emerge from the beam shearing system they contain more than 50 percent of the said photon flux and the chief rays of the two separate beams are substantially parallel to each other; and

an optical system focusing the said two separate beams of light emerging from the said beam shearing system onto an exit pupil; and

a detector located at the exit pupil.

13. The static interferometer in claim 12 wherein:

the detector comprises a detector array, read out electronics and a data processing system.

14. The static interferometer in claim 13 wherein:

the detector array records the intensity of the radiation incident on its pixels;

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1   the read out electronics digitizes the intensity
2   measurements made by the detector array and transfers
3   them to the data processing system; and

4   the data processing system manipulates the
5   digitized measurements to obtain information about the
6   spectrum of said incident radiation.

1 15. The static interferometer in claim 14 wherein:

2   the data processing system performs Fast Fourier
3   Transforms on the digitized measurements to obtain the
4   spectral composition of the incident radiation;

1 16. The static interferometer in claim 14 wherein:

2   the data processing system convolves the
3   digitized measurements with digital filters to detect
4   the presence or absence in the spectrum of the
5   incident radiation of frequencies of radiation
6   characteristically emitted or absorbed by particular
7   substances.

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1 17. The static interferometer in claim 12 wherein:

2   a single sided interferogram is created at said

3 exit pupil.

1 18. The static interferometer in claim 17 wherein:

2   the fore-optics focus the collected light in such

3 a way that the chief ray of the said collected light

4 describes paths through the said spectral resolving

5 system, which recombine on the said exit pupil at the

6 edge of the said detector array; and

7   said paths of the chief ray have substantially

8 the same optical path length.

1 19. The static interferometer in claim 18 wherein:

2   said fore-optics have a shifted pupil design.

1 20. The static interferometer in claim 12 wherein:

2   said fore-optics are telecentric.

1 21. The static interferometer of claim 12 wherein:

2   said optical system also focuses the said

3 separate beams of light emerging from the said beam

4 shearing system to create an image.

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1   22. The static interferometer of claim 21 wherein:

2   said optical system has an optical axis;

3   said exit pupil is located in one of the group

4   consisting of a tangential plane and a sagiital plane

5   relative to the said beam shearing system;

6   said image is located in the other of the group

7   consisting of a tangential plane and a sagiital plane

8   relative to the said beam shearing system; and

9   the exit pupil and the image are located at

10 substantially the same position along the optical

11 axis.

1   23. A beam shearing system comprising:

2   an entrance slit structure having an entrance

3   slit extending in a first direction for receiving a

4   beam of light having a photon flux within a

5   predetermined spectral pass band;

6   a beam splitter aligned at an angle to the first

7   direction so that the received beam of light is split

8   into two separate beams;

9   a reflective subsystem having a plurality of

10 reflective surfaces defining separate light paths of

11 equal optical path length for the two separate beams,

12 the reflective surfaces arranged such that one of the

13 separate beams undergoes one reflection and the other

14 of the separate beams undergoes three reflections and

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1   that when the two beams emerge from the beam shearing

2   system they contain more than 50 percent of the said

3   photon flux.

1   24.   A static interferometer comprising:

2   fore-optics for collecting light and collimating

3   into a beam, the fore-optics possessing an exit pupil;

4   a spectral resolving system comprising:

5   an   entrance   slit   structure   having   an

6   entrance slit extending in a first direction for

7   receiving a beam of light having a photon flux

8   within a predetermined spectral pass band;

9   a beam shearing system comprising:

10   a beam splitter aligned at an angle to

11   the first direction so that the received

12   beam of light is split into two separate

13   beams;

14   a   reflective   subsystem   having   a

15   plurality of reflective surfaces defining

16   separate light paths of equal optical path

17   length for the two separate beams, the

18   reflective surfaces arranged such that one

19   of   the   separate   beams   undergoes   one

20   reflection and the other of the separate

21   beams undergoes three reflections and that

22   when the two beams emerge from the beam

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1   shearing system they contain more than 50

2   percent of the said photon flux; and

3   a detector located at said exit pupil where the

4   two beams emerging from the beam shearing system

5   converge.

1   25. The static interferometer in claim 24 wherein:

2   the detector comprises a detector array, read

3   out electronics and a data processing system.

1   26. The static interferometer in claim 25 wherein:

2   the detector array records the intensity of the

3   radiation incident on its pixels;

4   the read out electronics digitizes the intensity

5   measurements made by the detector array and transfers

6   them to the data processing system; and

7   the data processing system manipulates the

8   digitized measurements to obtain information about the

9   spectrum of said incident radiation.

1   27. The static interferometer in claim 26 wherein:

2   the data processing system performs Fast Fourier

3   Transforms on the digitized measurements to obtain the

4   spectral composition of the incident radiation;

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1 28. The static interferometer in claim 27 wherein:

2   the data processing system convolves the
3 digitized measurements with digital filters to detect
4 the presence or absence in the spectrum of the
5 incident radiation of frequencies of radiation
6 characteristically emitted or absorbed by particular
7 substances.

1 29. The static interferometer in claim 24 which further
2 comprises:

3   an anamorphic optical system possessing an
4 optical axis;

5   the exit pupil being perpendicular to the optical
6 axis;

7   the optical system focusing the two beams
8 emerging from the beam shearing system to create an
9 image; and

10   the image being perpendicular to the exit pupil
11 and perpendicular to the optical axis.

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SPATIALLY MODULATED INTERFEROMETER

AND BEAM SHEARING DEVICE THEREFOR

ABSTRACT OF THE DISCLOSURE

5   A spatially modulated interferometer incorporates a beam shearing system having a plurality of reflective surfaces defining separate light paths of equal optical path length for two separate output beams. The reflective surfaces are arranged such that when the two beams emerge
10 from the beam shearing system they contain more than 50 percent of the photon flux within the selected spectral pass band. In one embodiment, the reflective surfaces are located on a number of prism elements combined to form a beam shearing prism structure. The interferometer
15 utilizing the beam sharing system of the invention includes fore-optics for collecting light and focusing it into a beam to be sheared, and a detector located at an exit pupil of the device. In a preferred embodiment, the interferometer has no moving parts.

20

244251-1

Fore-optics — 12

Beam shearing system — 14

Fourier optical system — 16

Detector array — 18

Readout Electronics and Data processing system — 20

10

FIGURE 1

FIGURE 3

16

36

20

18

X
Z

14

32

34

20

18

Y
Z

30

26

10
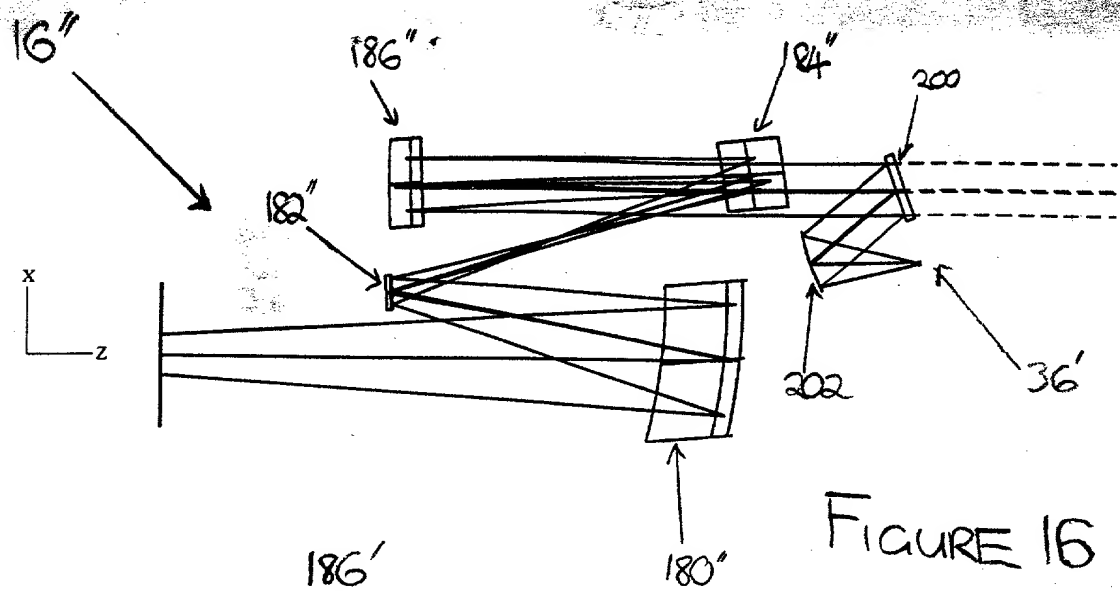
24

16

12

22

FIGURE 2

FIGURE 4

50

66

68

64

56

52

58

72

70

74

60

54

62

76

Δs

32

30

Y

Z
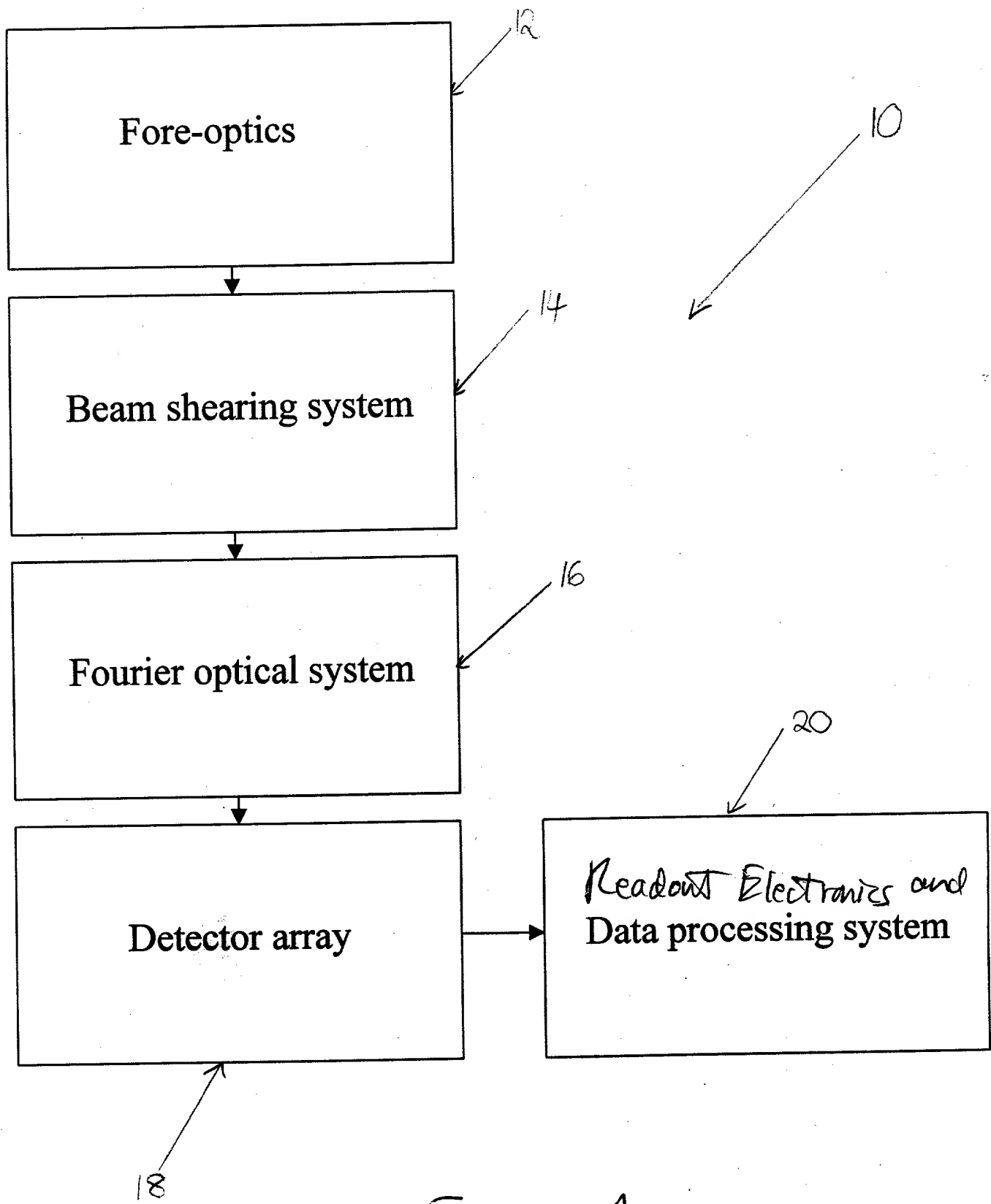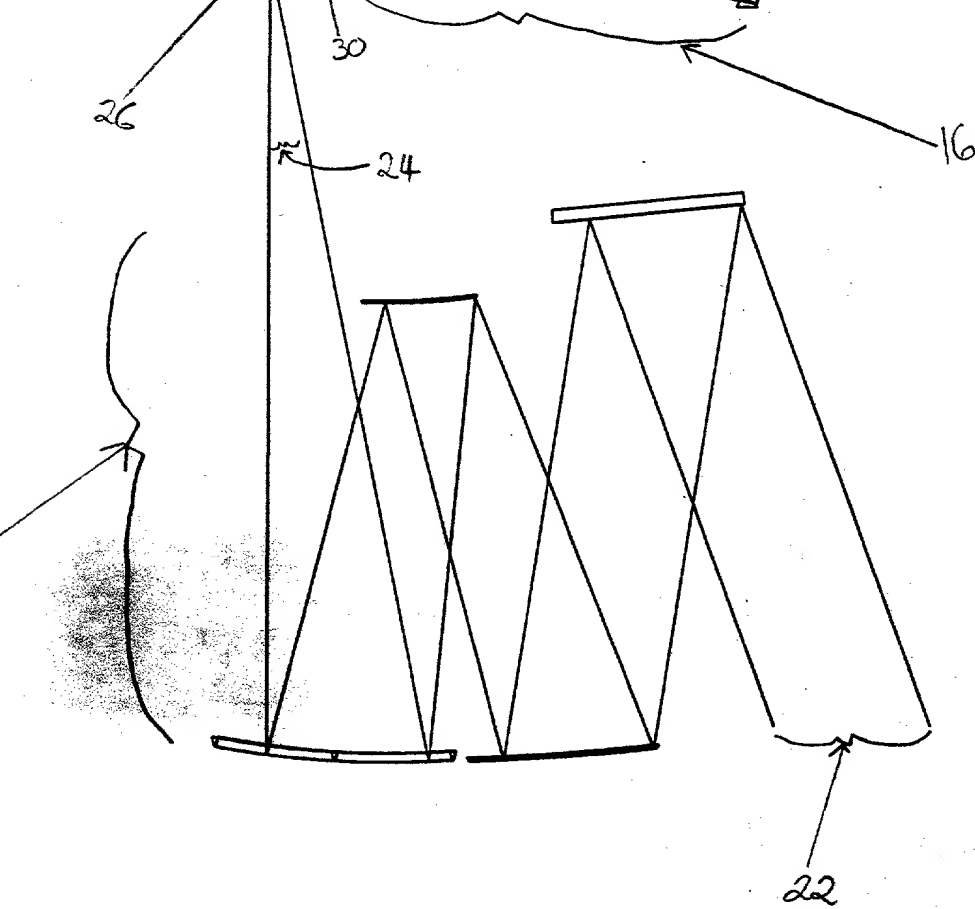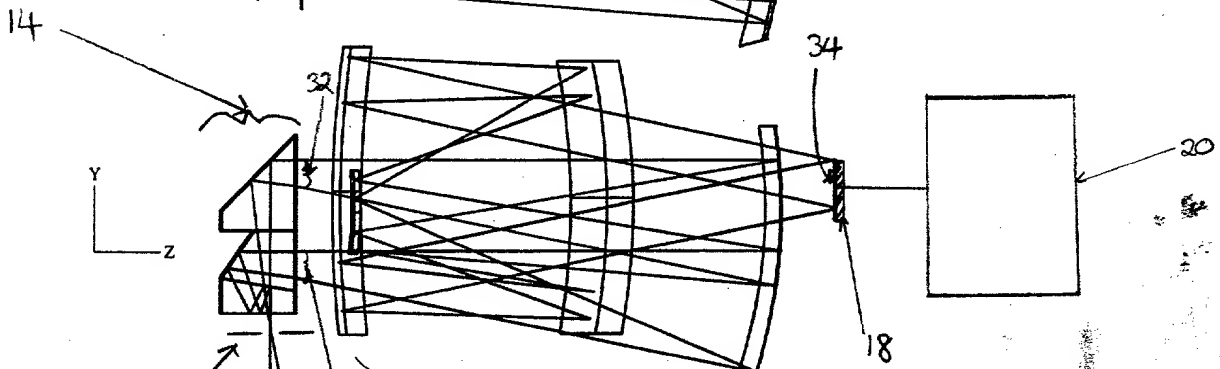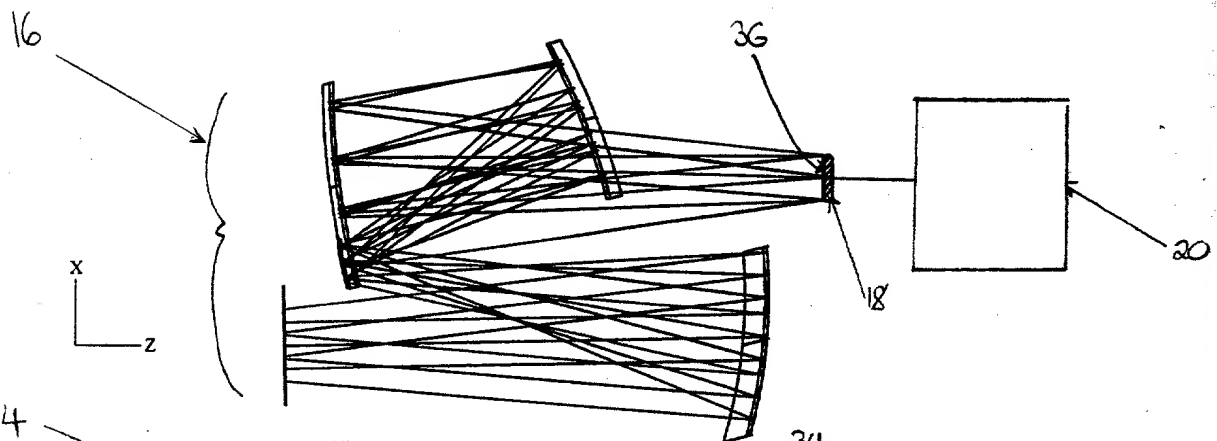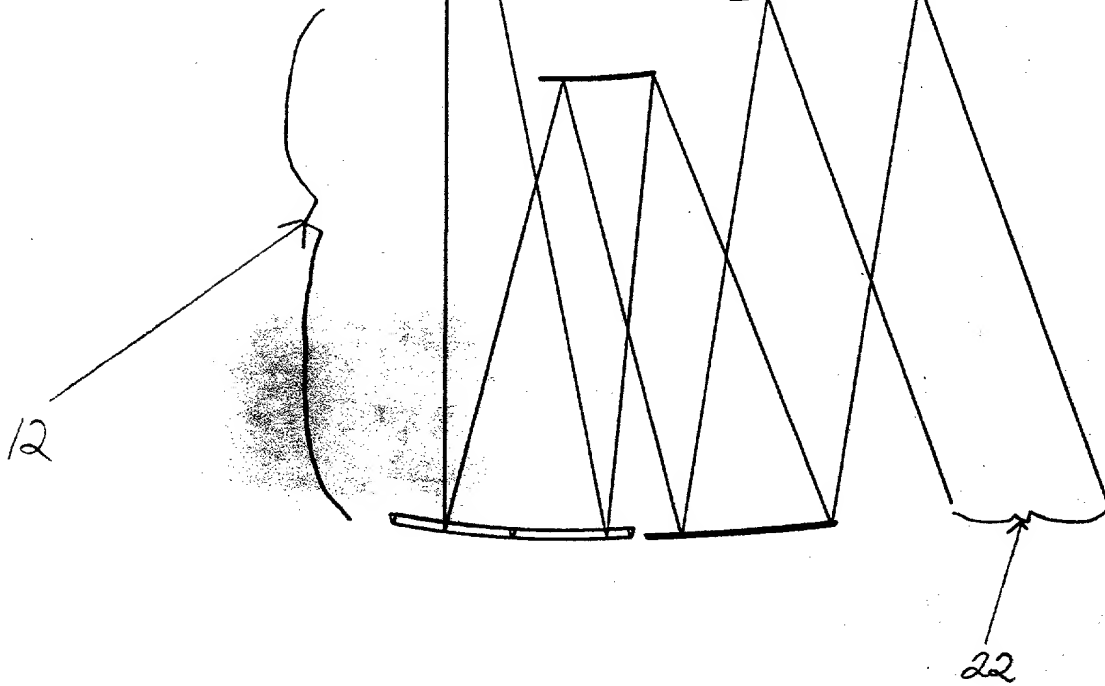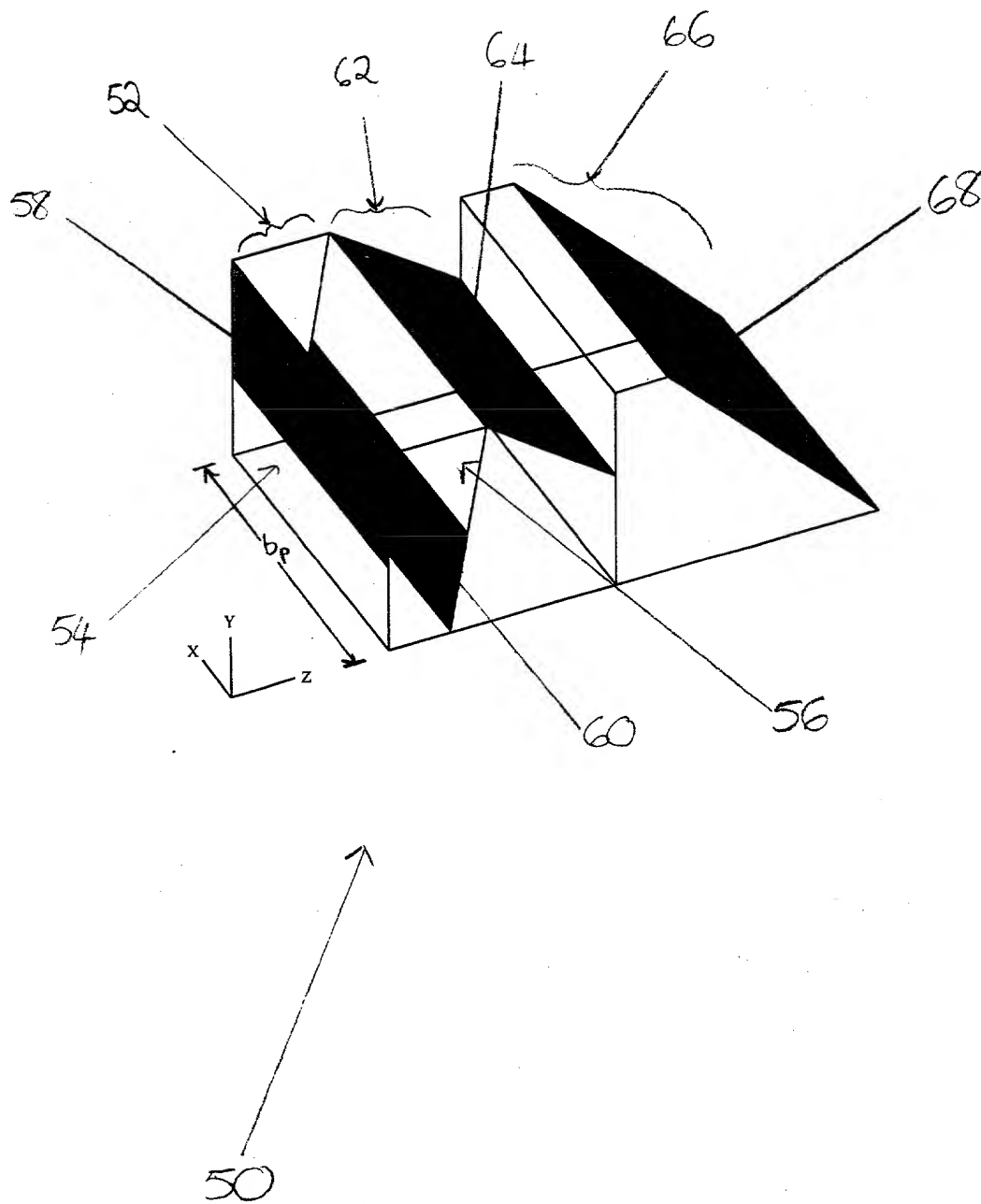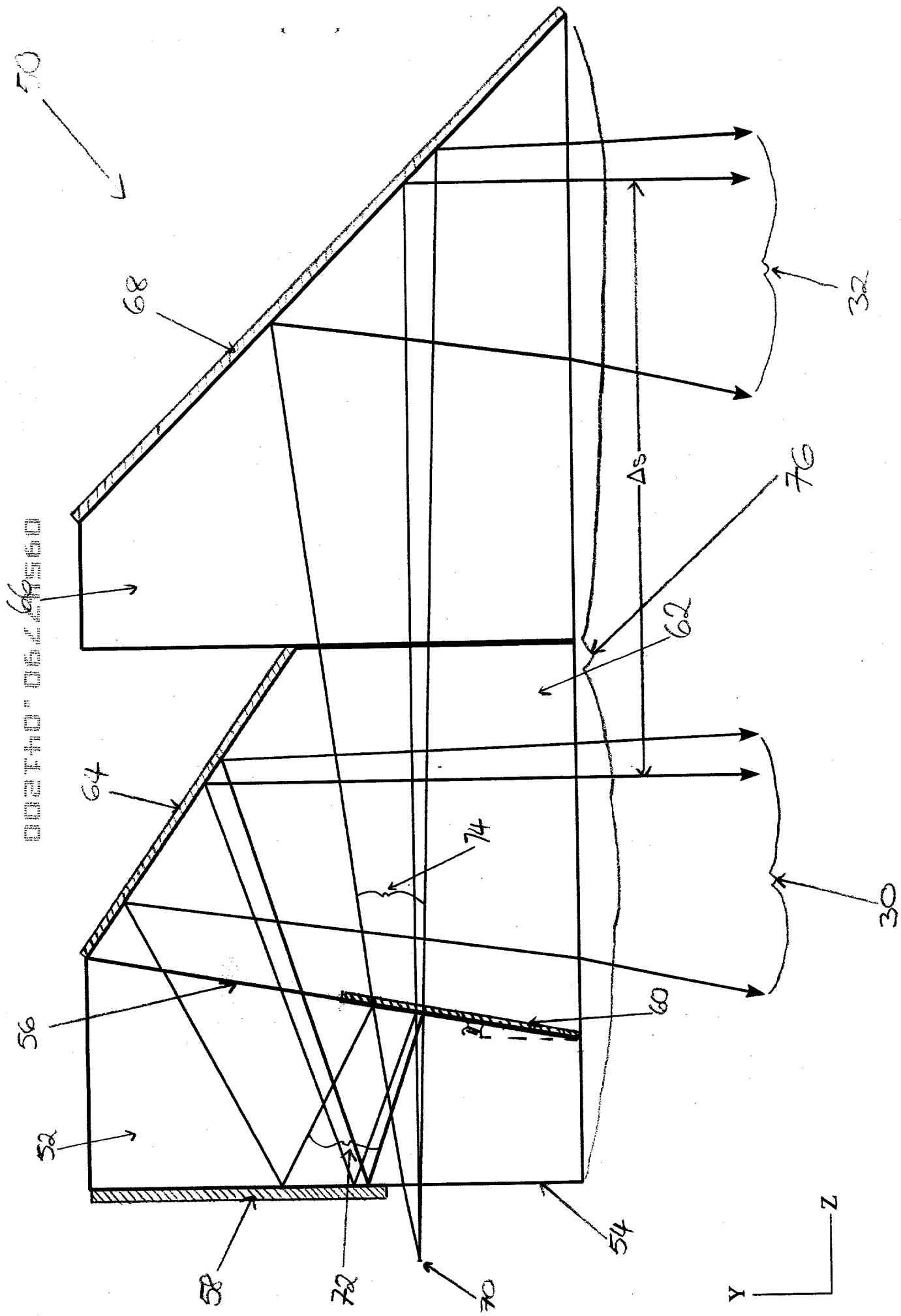
FIGURE 5

FIGURE 6

FIGURE 7
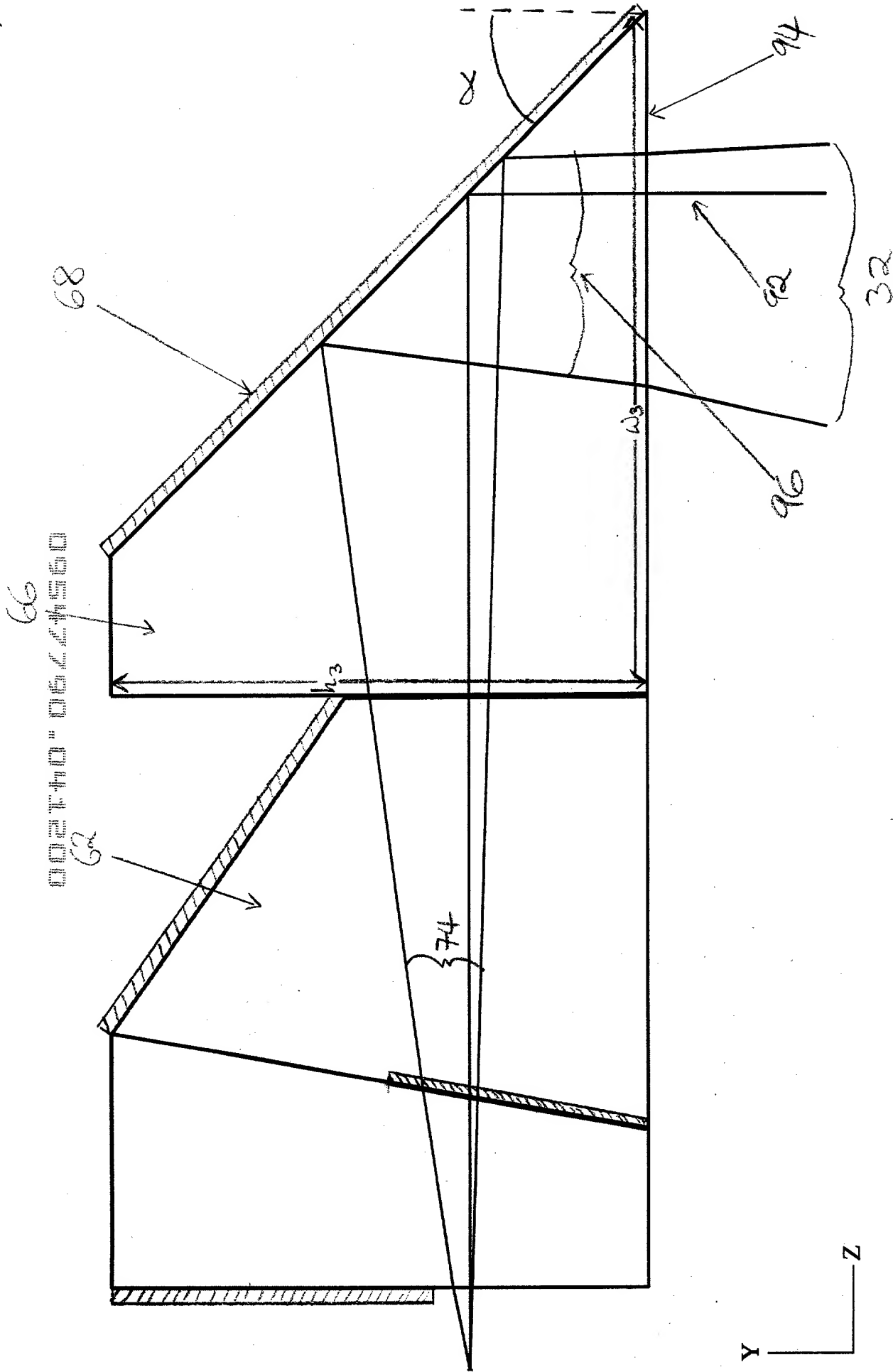
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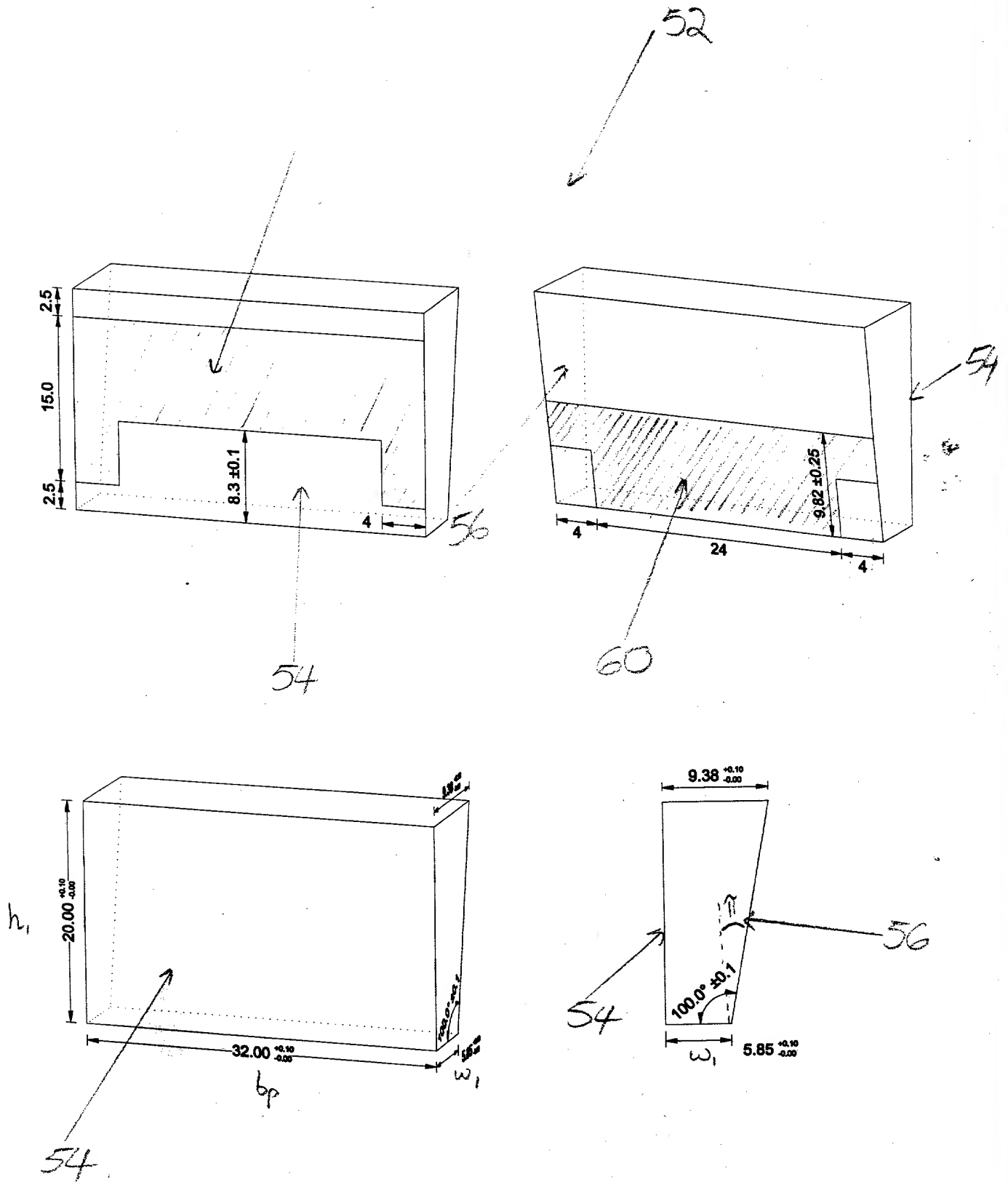
52

54

56

60

54

h_1

20.00 +0.10 -0.00

32.00 +0.10 -0.00

b_p

ω_1

54

9.38 +0.10 -0.00

56

54

100.0° ±0.1

ω_1

5.85 +0.10 -0.00

2.5

15.0

2.5

8.3 ±0.1

4

9.82 ±0.25

4

24

4

FIGURE 8A

62

64

64

h_2

b_p

ω_2

84

125.0° ±0.1

80.0° ±0.1

16.00 $^{+0.00}_{-0.10}$

ω_2

64

11.27 $^{+0.10}_{-0.00}$

32.00 $^{+0.10}_{-0.00}$

66

68

68

5.15 $^{+0.00}_{-0.10}$

α

45.0° ±0.1

25.15 $^{+0.00}_{-0.10}$

ω_3

94

h_3

20.00 $^{+0.10}_{-0.00}$

32.00 $^{+0.10}_{-0.00}$

b_p

ω_3

94
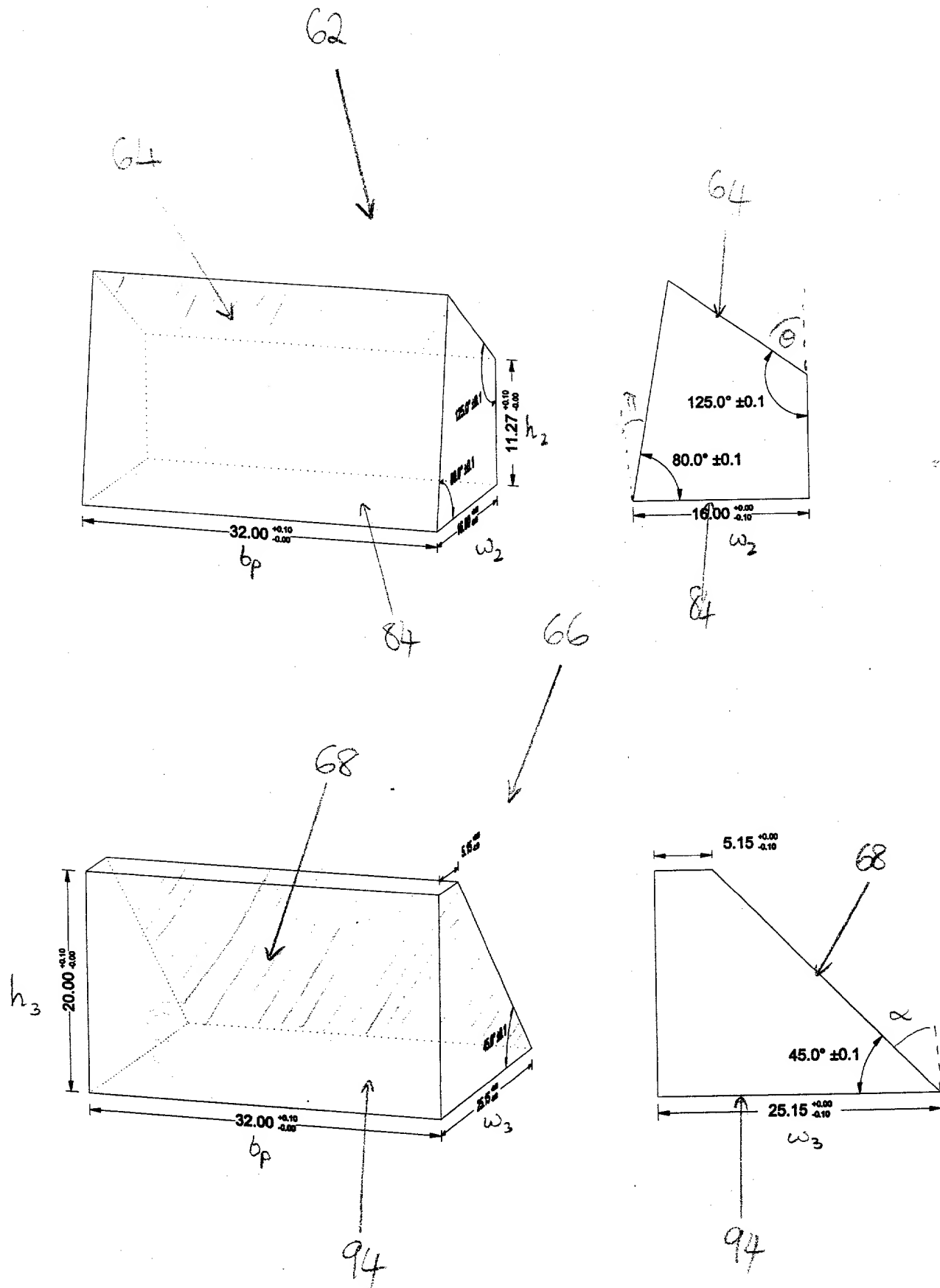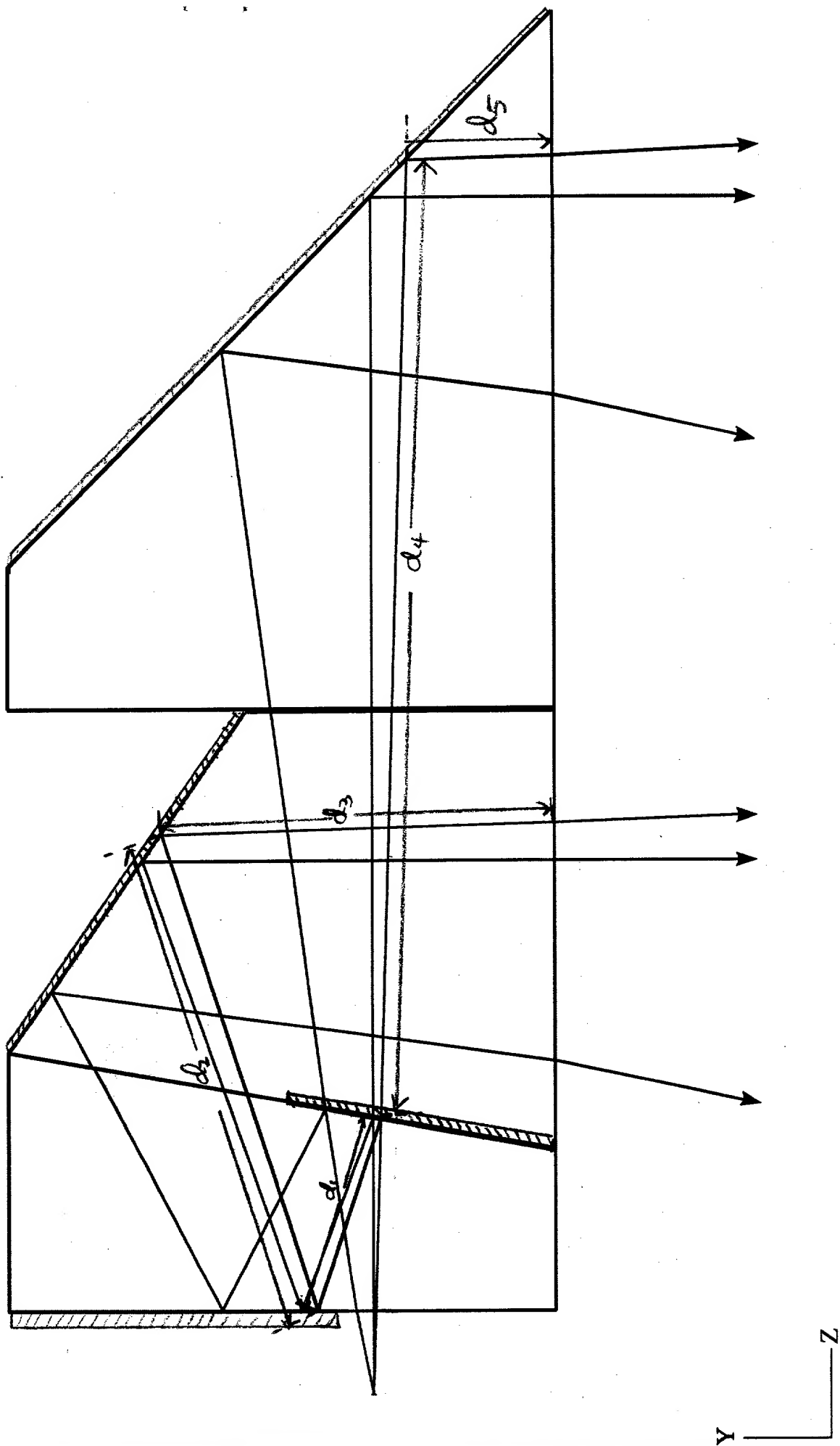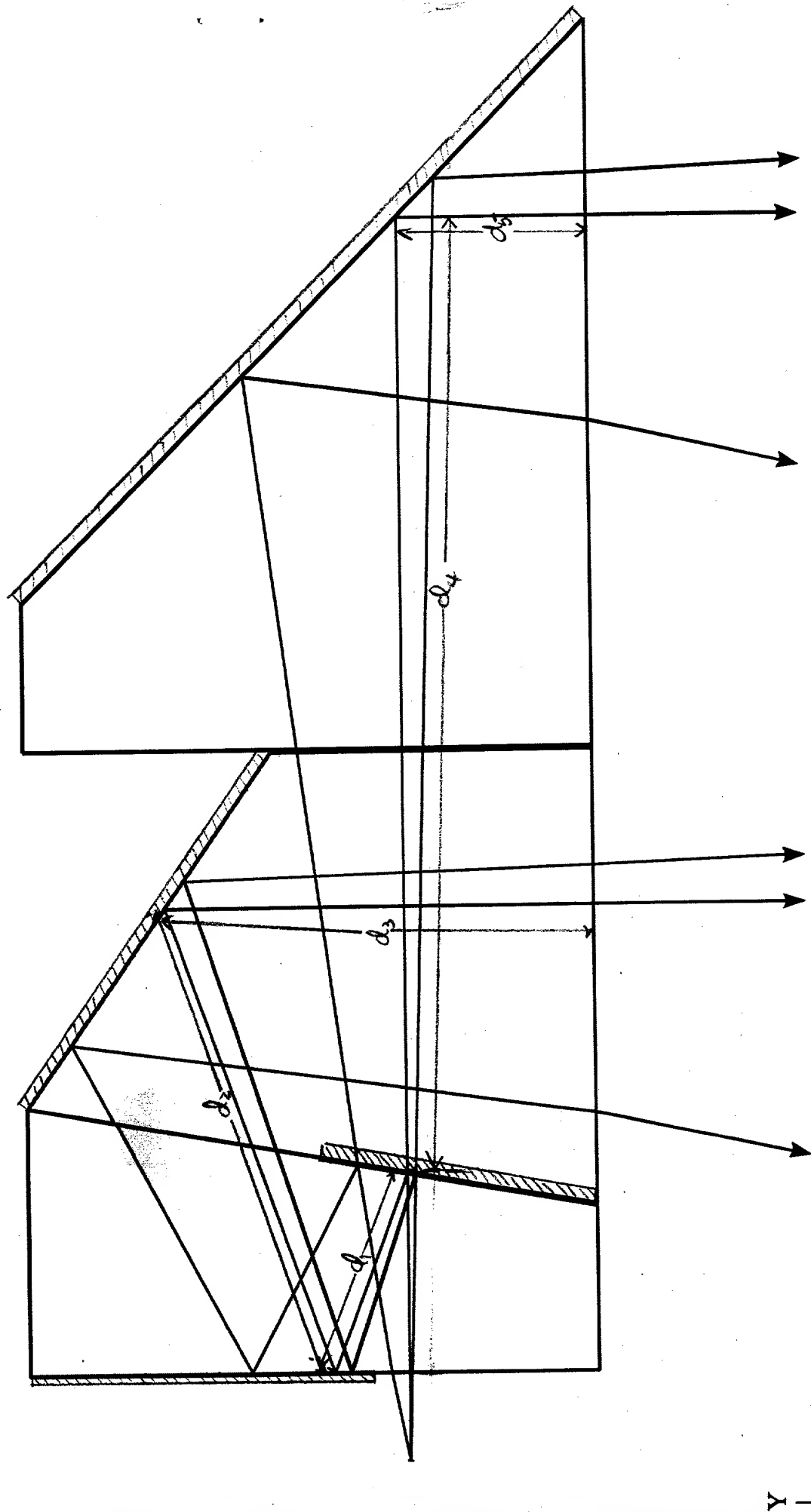
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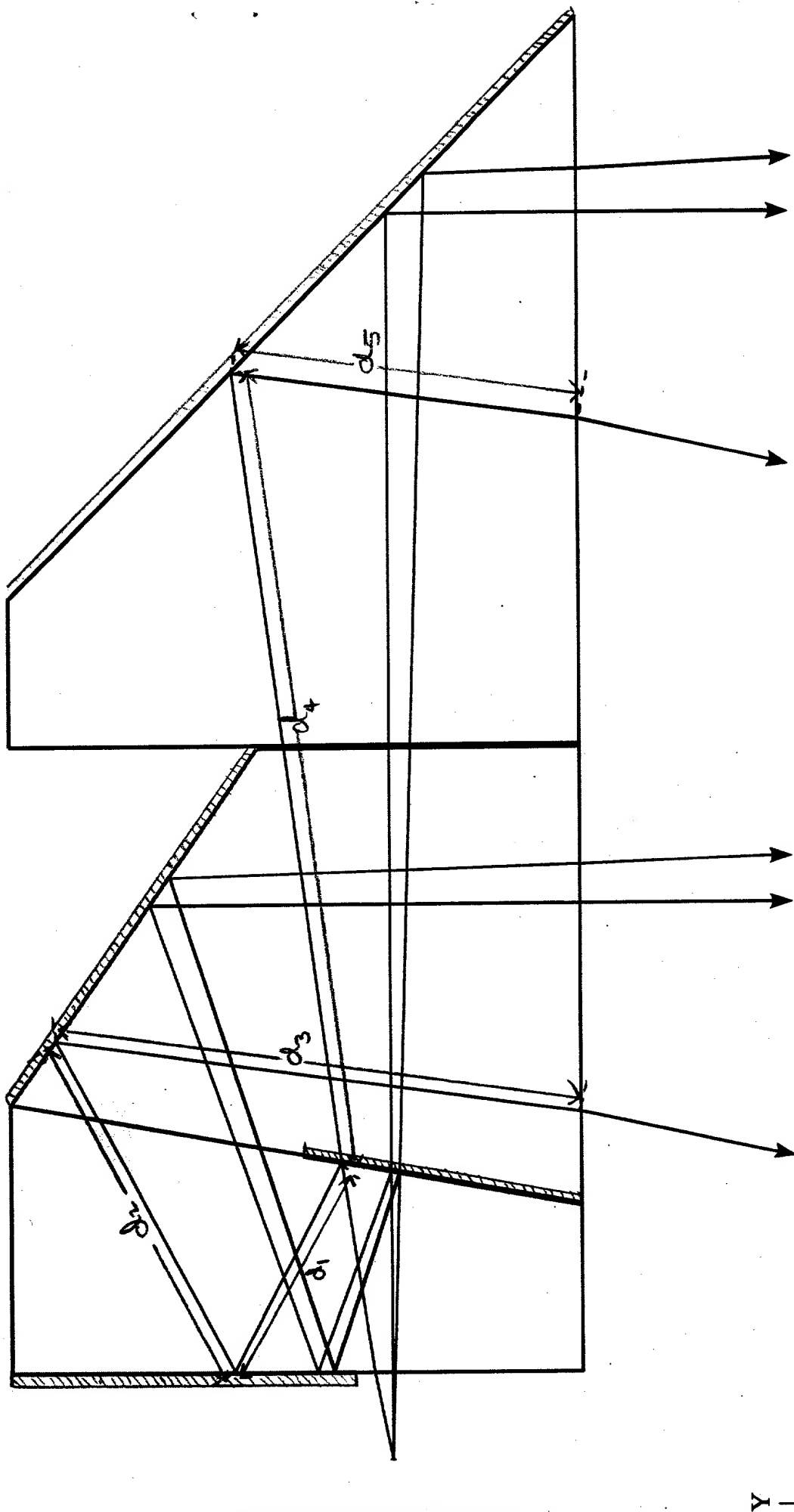
FIGURE 9

FIGURE 10

FIGURE 11

FIGURE 11A

FIGURE 11 B

168

170

164

160

168

162

FIGURE 12

16

184

190

36

186

182

x
z

FIGURE 13

180

192

194

34

32

30

196

182

186

184

FIGURE 14

16

16"

186"

184"

200

182"

x
z

202

36'

180"

FIGURE 16

186'

184'

182'

192'

37'

Y
z

194'

180'
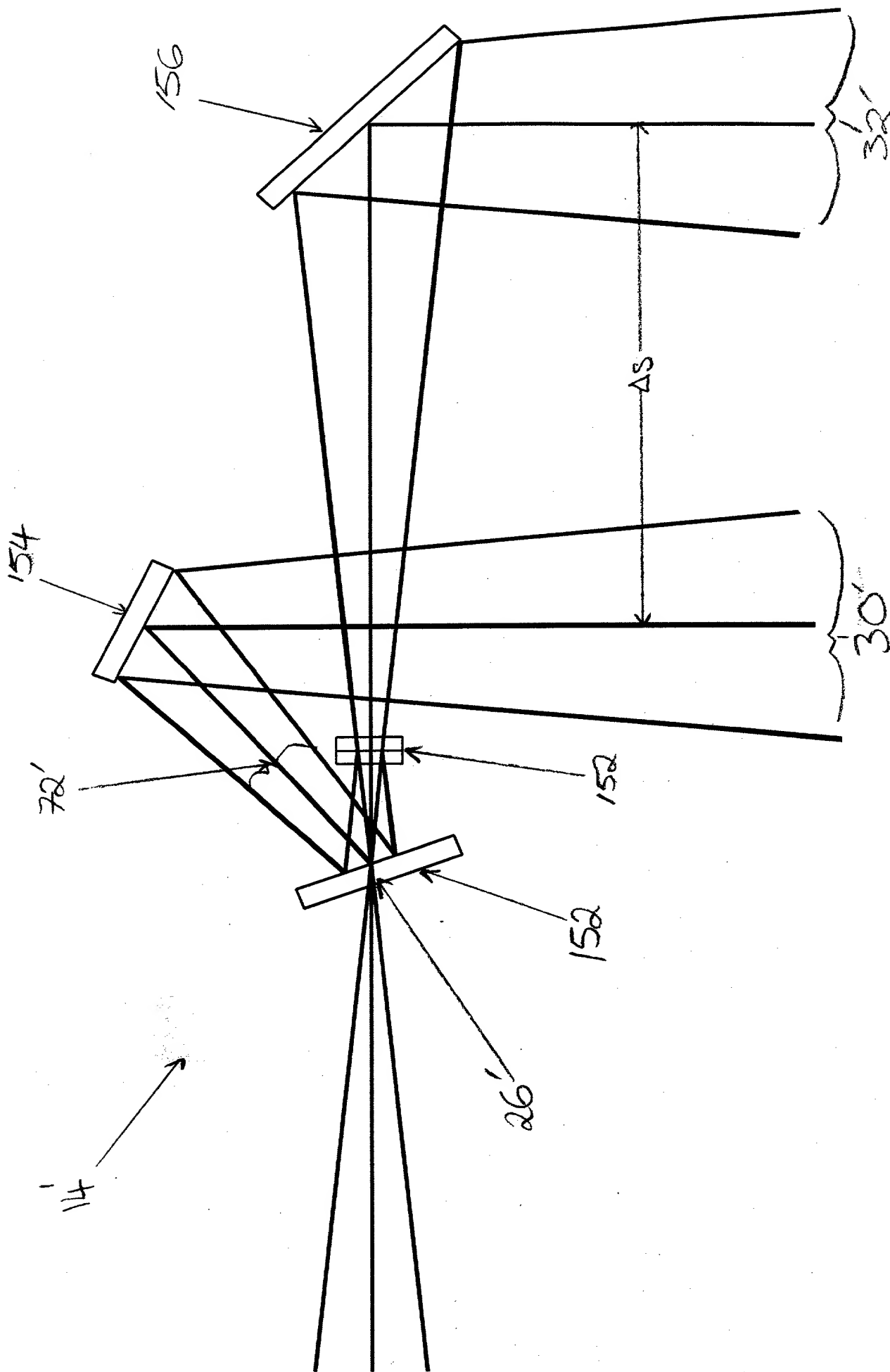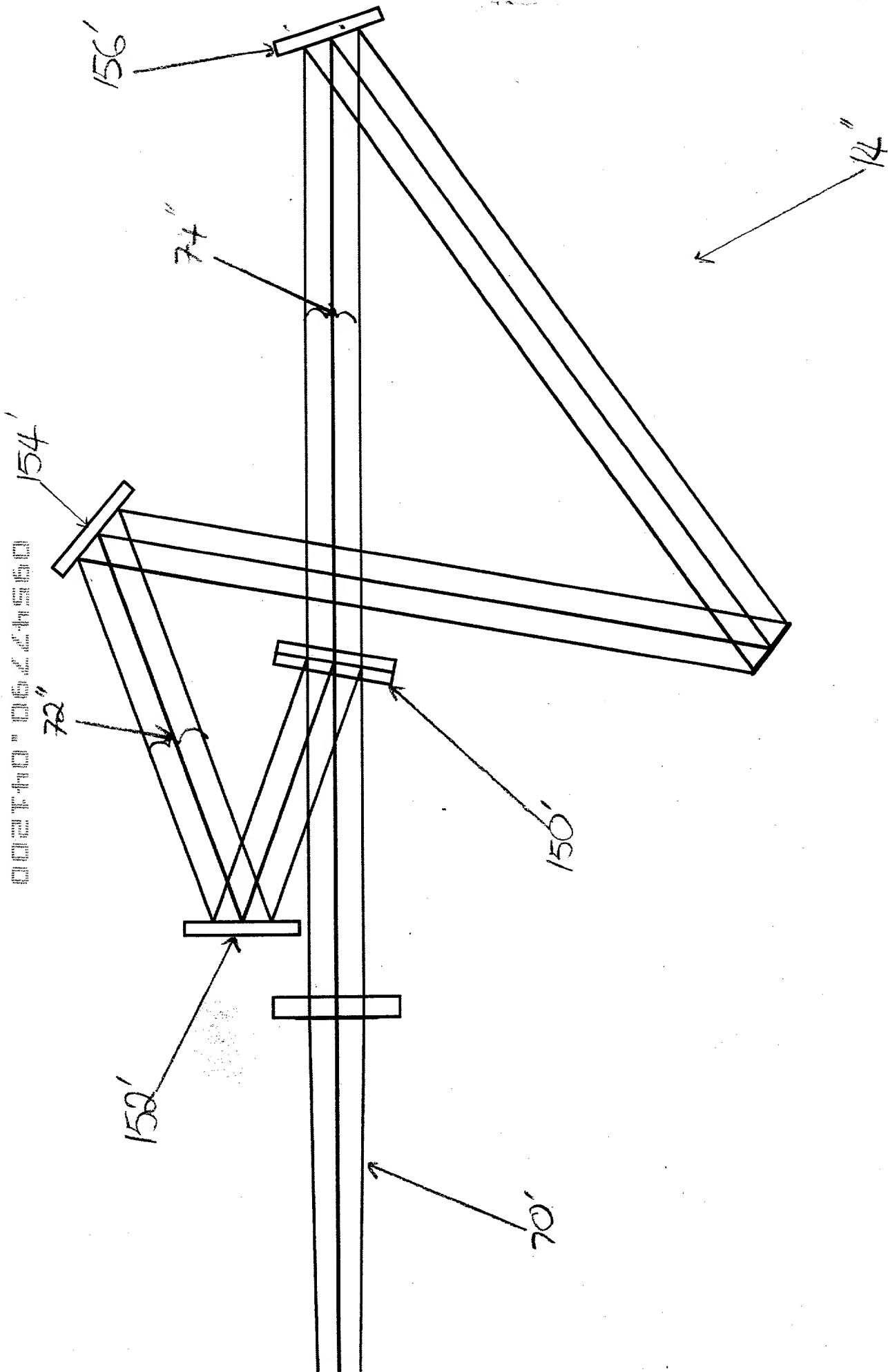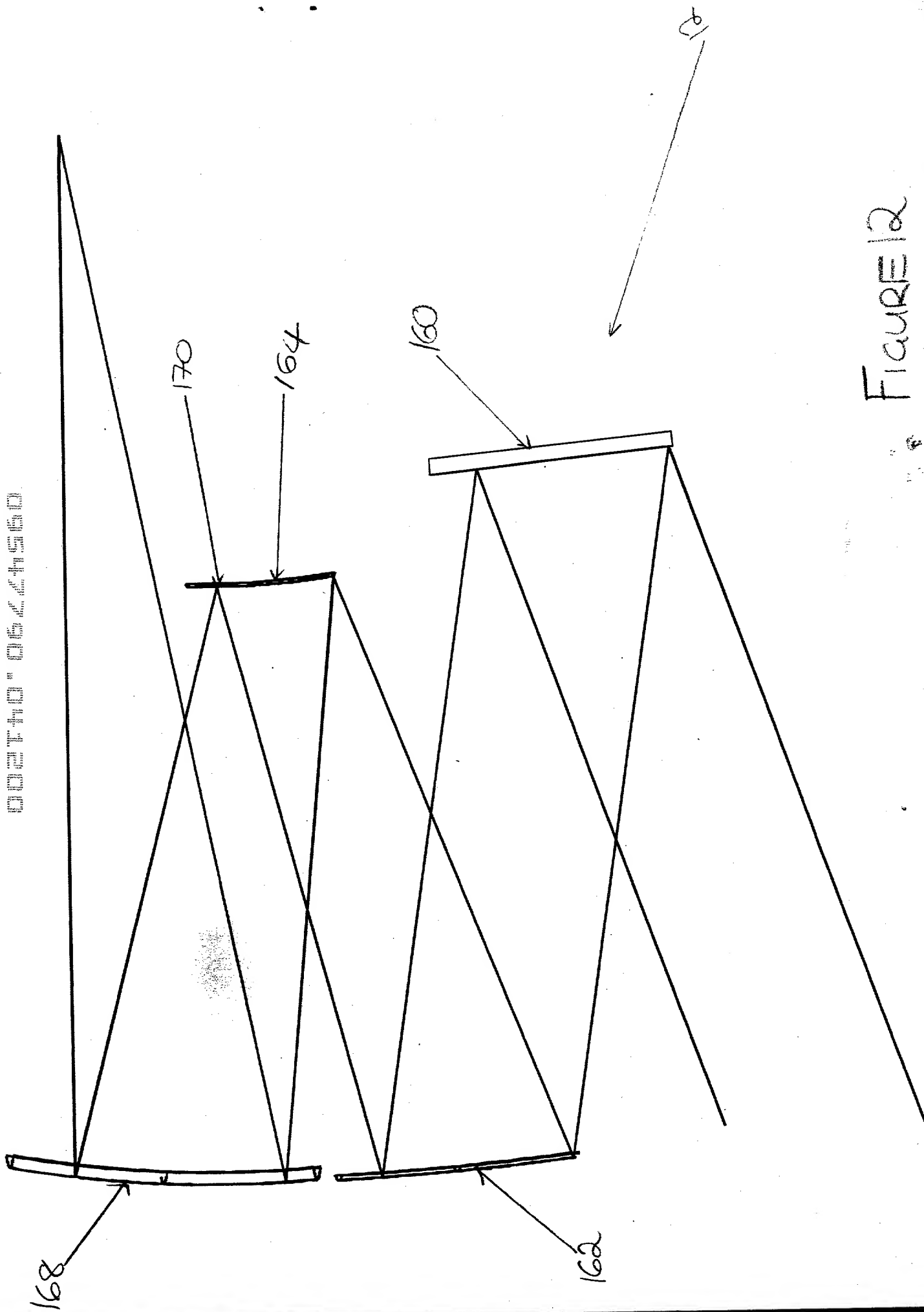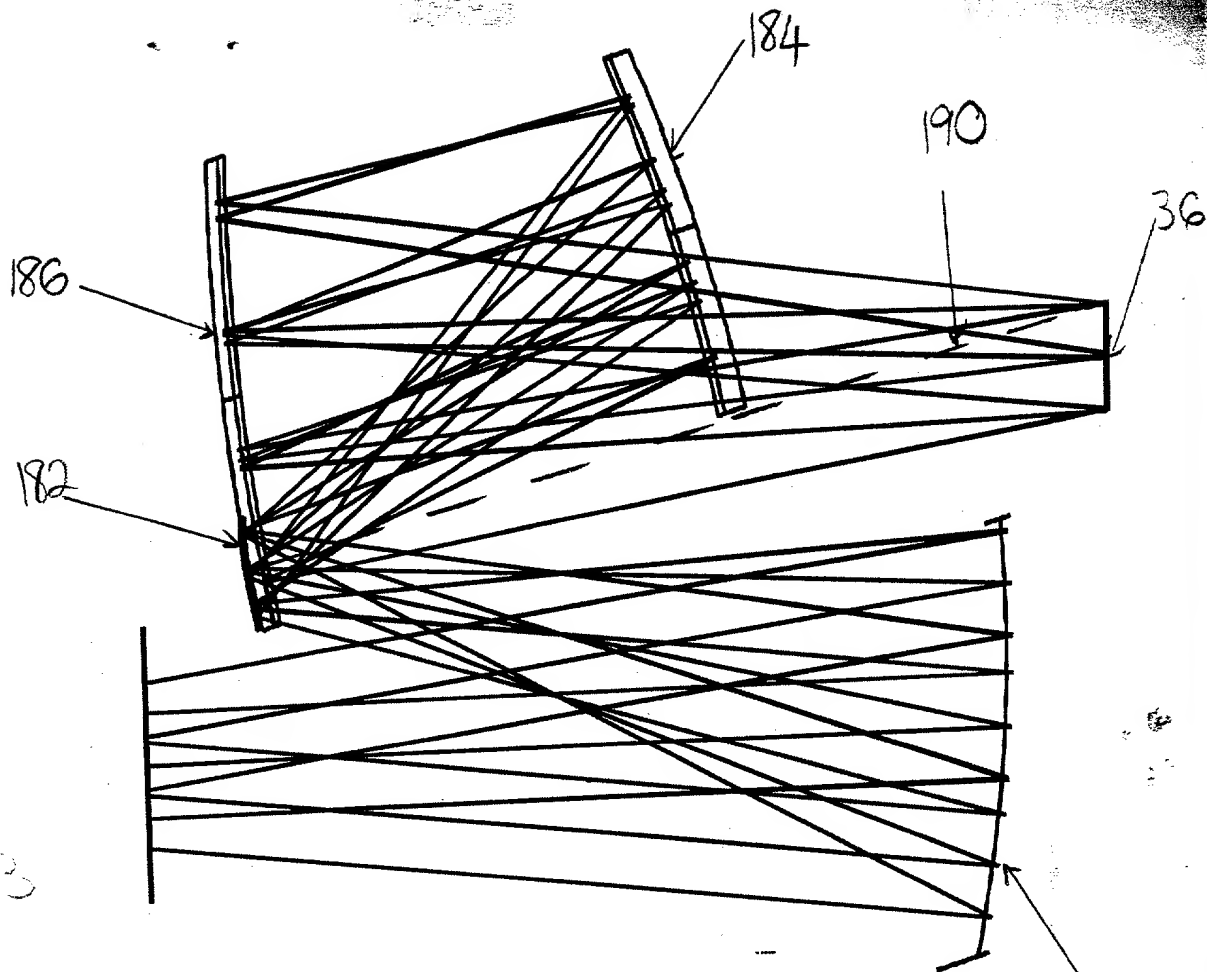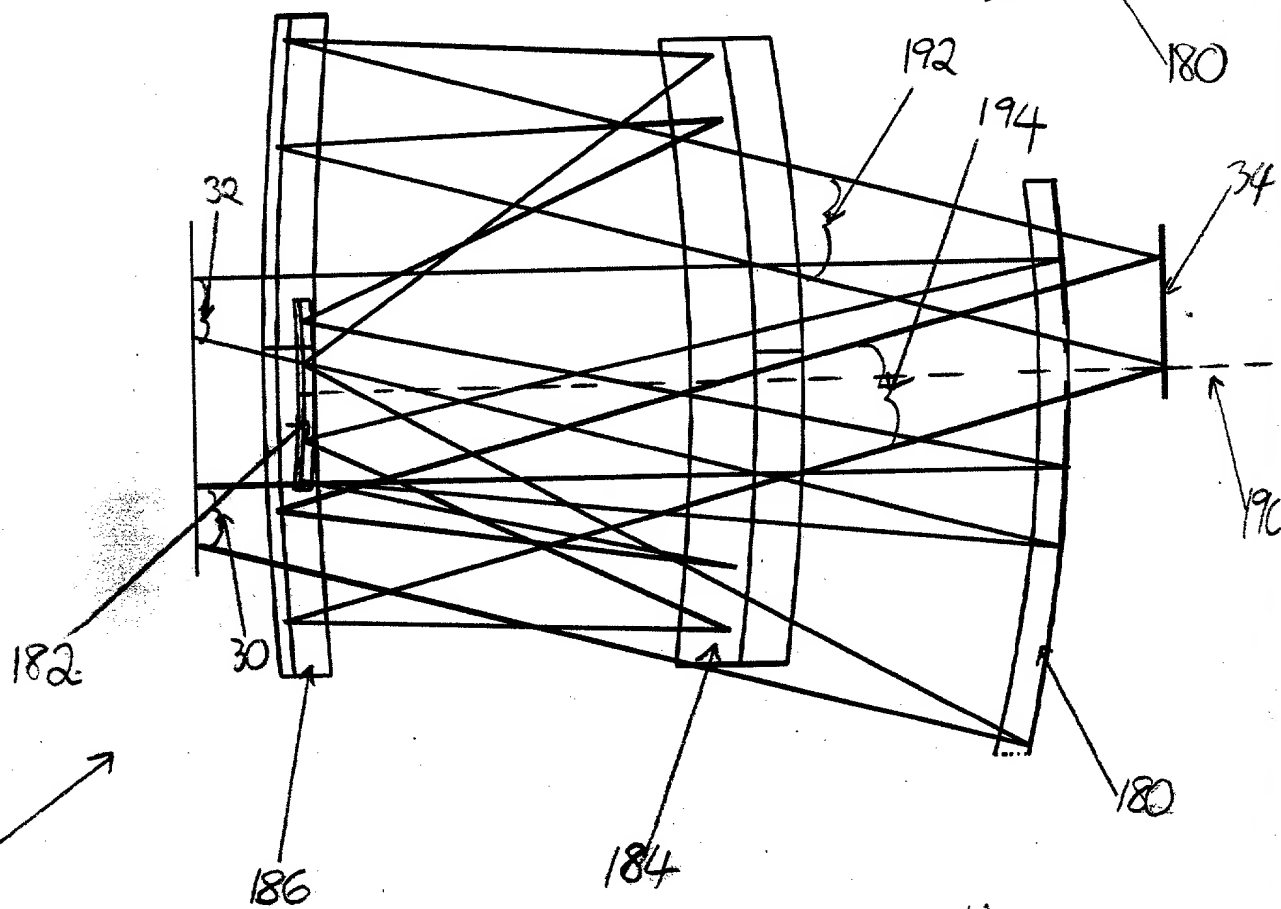
16'
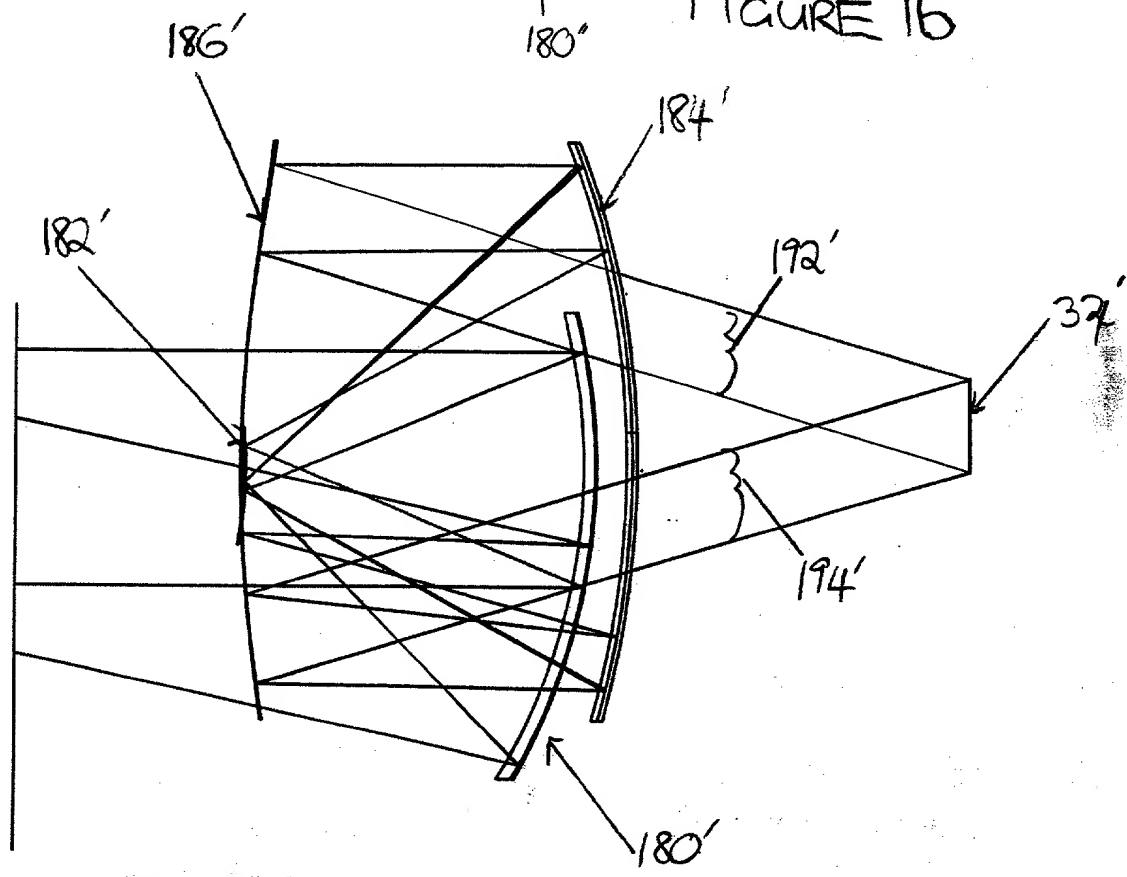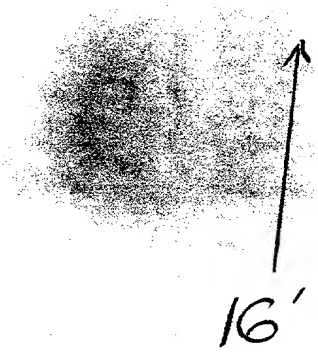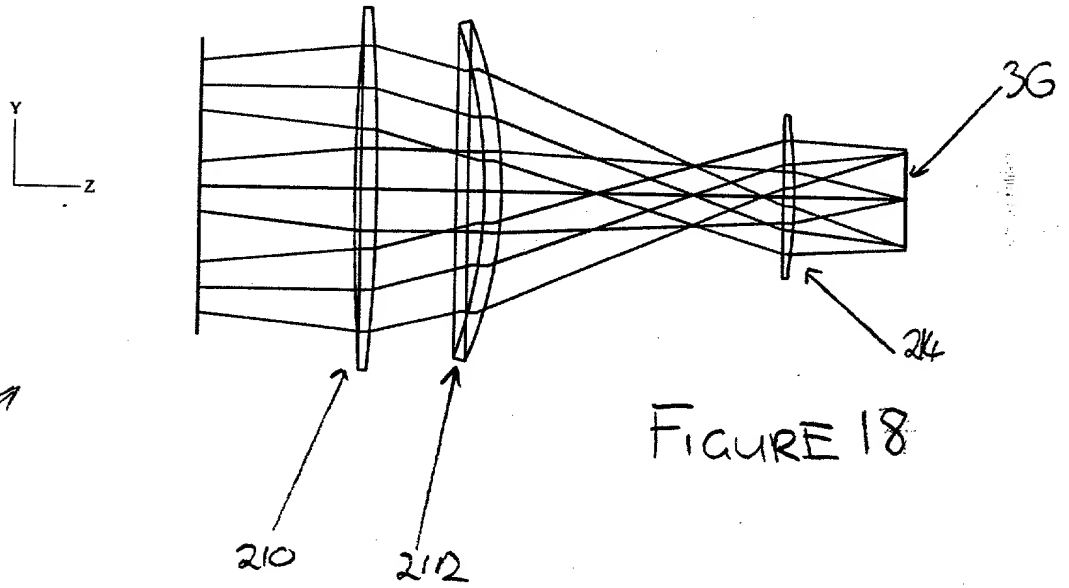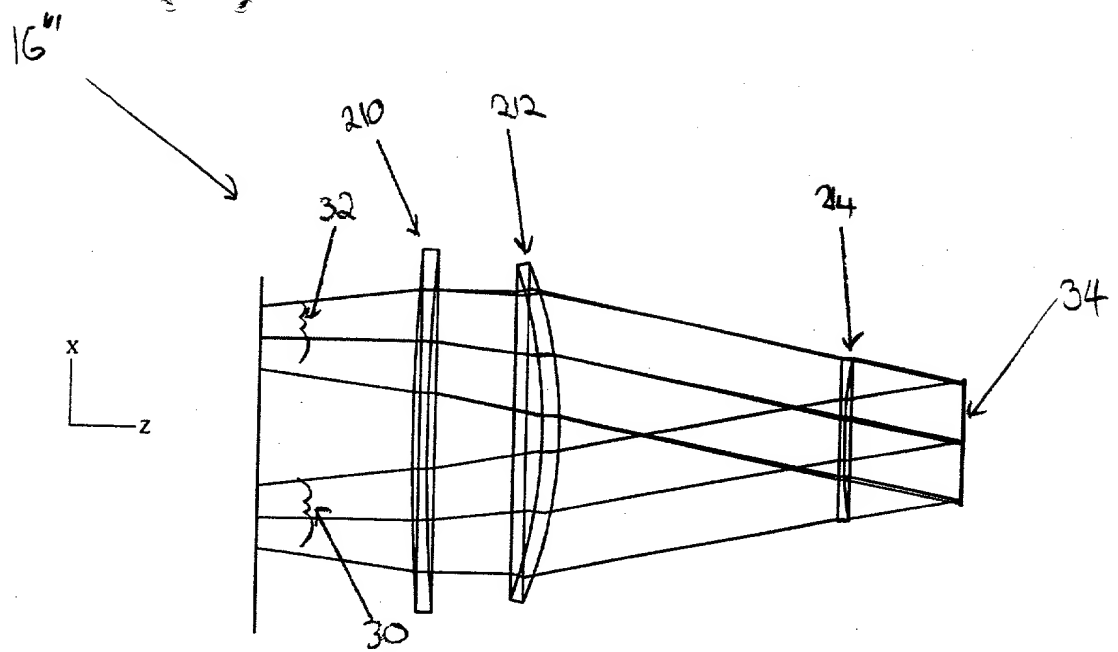
FIGURE 15

FIGURE 17

FIGURE 18
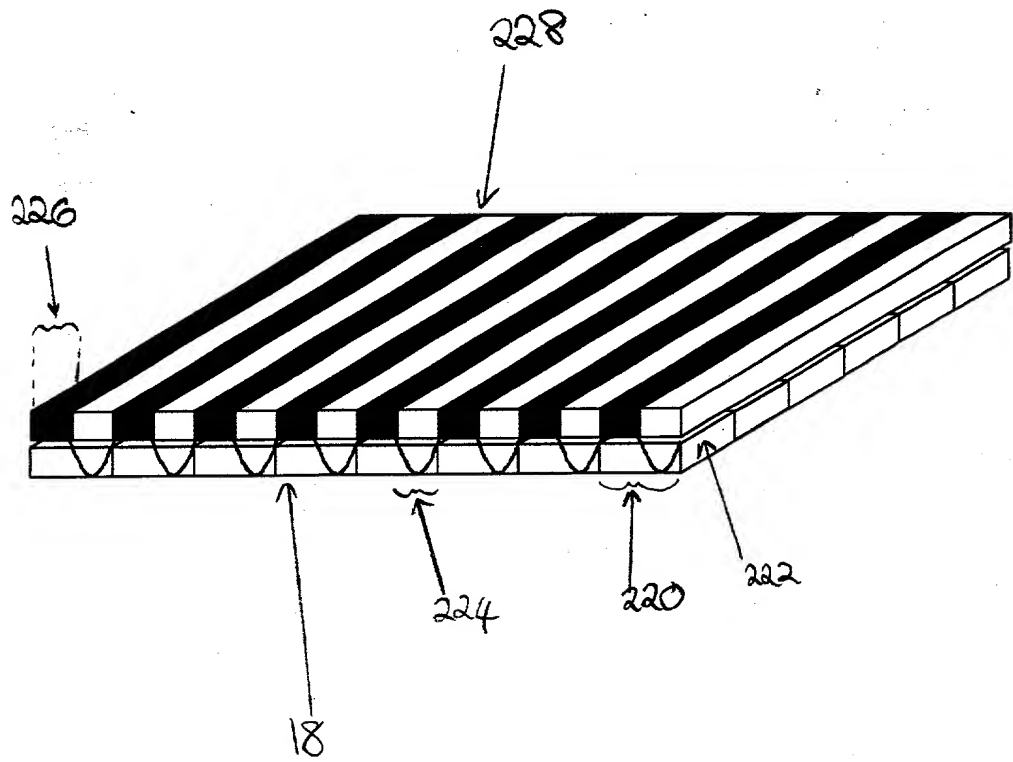
FIGURE 19

Docket No. : 39260/RAG/C766

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled SPATIALLY MODULATED INTERFEROMETER AND BEAM SHEARING DEVICE THEREFOR, the specification of which is attached hereto unless the following is checked:

___ was filed on ___ as United States Application Number or PCT International Application Number ___ and was amended on ___ (if applicable).

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to patentability as defined in 37 CFR § 1.56.

I hereby claim foreign priority benefits under 35 U.S.C. § 119(a)-(d) or § 365(b) of the foreign application(s) for patent or inventor's certificate, or § 365(a) of any PCT International application which designated at least one country other than the United States, listed below and have also identified below, any foreign application for patent or inventor's certificate, or PCT International application having a filing date before that of the application on which priority is claimed.

Prior Foreign Application(s)

Application Number   Country   Filing Date (day/month/year)   Priority Claimed

I hereby claim the benefit under 35 U.S.C. § 119(e) of any United States provisional application(s) listed below.

Application Number   Filing Date

60/129,383   April 13, 1999

I hereby claim the benefit under 35 U.S.C. § 120 of any United States application(s), or any PCT International application designating the United States, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT International application in the manner provided by the first paragraph of 35 U.S.C. § 112, I acknowledge the duty to disclose information which is material to patentability as defined in 37 CFR § 1.56 which became available between the filing date of the prior application and the national or PCT International filing date of this application:

Application Number   Filing Date   Patented/Pending/Abandoned

POWER OF ATTORNEY: I hereby appoint the following attorneys and agents of the law firm CHRISTIE, PARKER & HALE, LLP to prosecute this application and any international application under the Patent Cooperation Treaty based on it and to transact all business in the U.S. Patent and Trademark Office connected with either of them in accordance with instructions from the assignee of the entire interest in this application;

or from the first or sole inventor named below in the event the application is not assigned; or from __ in the event the power granted herein is for an application filed on behalf of a foreign attorney or agent.

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Hayden A. Carney	(22,653)	Grant T. Langton	(39,739)	Phuong-Quan Hoang	(41,839)
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LeRoy T. Rahn	(20,356)	Daniel R. Kimbell	(34,849)	Jun-Young E. Jeon	(43,693)
Richard D. Seibel	(22,134)	Craig A. Gelfound	(41,032)	Marc A. Karish	(44,816)
Walter G. Maxwell	(25,355)	Syed A. Hasan	(41,057)	John F. O'Rourke	(38,985)
William P. Christie	(29,371)	Kathleen M. Olster	(42,052)	Richard J. Paciulan	(28,248)
David A. Dillard	(30,831)	Daniel M. Cavanagh	(41,661)	Josephine E. Chang	(46,083)
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Vincent G. Gioia	(19,959)	Lucinda G. Auciello	(42,270)	Steven E. Johnson	(P-45,916)
Edward R. Schwartz	(31,135)	Norman E. Carte	(30,455)	Frank L. Cire	(42,419)
John D. Carpenter	(34,133)	Joel A. Kauth	(41,886)	Harold E. Wurst	(22,183)
David A. Plumley	(37,208)	Patrick Y. Ikehara	(42,681)	Robert A. Green	(28,301)
Wesley W. Monroe	(39,778)	Mark Garscia	(31,953)		

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P.O. Box 7068, Pasadena, CA 91109-7068

I declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Full name of sole or first joint inventor FRANCIS M. REININGER	Inventor's signature *Francis M. Reininger*	Date April 12, 2000
Residence and Post Office Address 12 Candlebush, Irvine, California 92612		Citizenship US

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